Pacific Island Network – Inventory & Monitoring Program

Appendix A. Part B: Topical Workgroup Reports

Monitoring Plan

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Preface

The network is planning, designing, and implementing its Vital Signs monitoring program. The National Park Service Monitoring Program website, http://science.nature.nps.gov/im/monitor/, provides additional background information on the history, institutional guidance, and current status of the NPS Monitoring Program.

National Park Service monitoring program guidance outlines a Network approach to monitoring (http://science.nature.nps.gov/im/monitor/approach.htm); incorporating a 3-phase planning and design process that will extend over four years. Phase 1 (FY2003), defines goals, and sets preliminary objectives, summarizes existing data and understanding (including evaluating and synthesizing existing data), and develops conceptual ecological models. These first 2 chapters build a foundation for Vital Signs prioritization and selection—fulfilled in the Phase 2 version (FY2004)—and will include an update of material prepared previously. A Phase 3 version (FY2005-FY2006) will encompass a complete monitoring plan.

These materials are currently in DRAFT form (as of 3/1/04). The authors have been asked to share these reports for comment in March 2004. In several cases, authors have only had several weeks to work on these materials, and this may be evident in the content of the report. Accordingly, we hope that comments can focus on helping us ensure we have identified the breadth and significance of natural resource and ecological issues in the Pacific Island Network.

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Terrestrial Invertebrate Fauna Workgroup Overview

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David Foote, Workgroup Lead

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Terrestrial and Aquatic Invertebrates Group Executive Summary

There are 9897 species of terrestrial arthropods recorded in the literature as occurring among the major Hawaiian Islands, including 5732 species that are endemic to these islands. When one considers other major groups of invertebrates, including molluscs, crustaceans, and annelids, the diversity approaches a figure that is an order of magnitude greater than species of flowering plants and two orders of magnitude greater than all vertebrate species combined. The challenge of the National Park Service is to move forward with the identification, prioritization and implementation of invertebrate monitoring programs in the Pacific while recognizing that a tremendous proportion of the biological diversity represented by invertebrates remains poorly known and uninventoried. The taxonomic impediments and lack of survey data are greater outside of the Hawaiian Islands and resource base inventories of invertebrates may have to precede the development of monitoring programs for sensitive native invertebrate fauna in larger Pacific Area parks, such as The National Park of American Samoa. Ten of the 11 National Parks in the Pacific Island network have habitat that can support native terrestrial and freshwater aquatic invertebrates. All parks in the network can contribute to monitoring programs for invasive alien invertebrates, such as incipient invasions of ants.

Invertebrate monitoring can address changes in the populations of native, alien, and rare or sensitive species. Like vegetation monitoring, native and alien invertebrate surveys, such as those associated with documenting recovery after ungulate removal studies, are an important part of long term monitoring for tracking the health of native ecosystems. Monitoring also includes detecting changes in terrestrial and aquatic invertebrate communities over time and across environmental gradients altered by patterns of long-term climate change. Community monitoring typically is concerned with successional patterns following alien species control programs or those associated with a forest decline event, or with tracking long-term trends in species composition. A monitoring system provides resource managers information essential to tracking invertebrate biodiversity, using as proxies those groups that are taxonomically well-characterized and accessible to monitoring. Monitoring programs for established alien invertebrates serves as the basis of integrated pest management programs that can be readily combined with other alien species detection and control efforts. Because invertebrate generation times are faster than those of vertebrates and plants, invertebrate monitoring programs serve as an early warning system for detecting habitat degradation on a timescale where intervention and recovery can occur more rapidly.

This summary is intended to be an initial overview of the current knowledge regarding terrestrial and aquatic invertebrate resources and current invertebrate monitoring in all Pacific Island National Parks. Because of the close association between most invertebrate and plant communities, this summary follows the format (and is in part an adaptation) of the Vegetation and Flora Working Group Summary. A summary of each park follows, including known resource base inventories of invertebrates, existing invertebrate resources, rare or focal endemic invertebrate species groups, alien invertebrate stressors, monitoring needs, and current monitoring efforts.

ALKA. The invertebrate resources of the newly-designated, 175-mile-long Ala Kahakai Trail have not been inventoried. The path, extent, and boundaries of the trail have not yet been defined.

AMME. American Memorial Park is a 133-acre coastal park on the island of Saipan in the Northern Marianas. No resource base inventory of invertebrates has been undertaken in AMME. The park is unlikely to support a diverse assemblage of native host-plant associated arthropods because it is dominated by alien plant species. However, the near-native mangrove wetland should be surveyed for odonates and other aquatic insect groups. A species of rare partulid snail was recently discovered in the wetland. The status of the alien ant community also deserves attention. Baseline transects established for vegetation monitoring in the wetland in the late 1980s could be used for timed-flight observations of dragonflies and other potentially sensitive native arthropods, as well as bait-station monitoring for ants.

HALE. Haleakala National Park on Maui has been the subject of several inventories for invertebrates, including a preliminary resource base inventory of the crater district and lower Kipahulu Valley, but the invertebrate resources of much of the park remain poorly known. Extensive elevational and moisture gradients on Haleakala, up to greater than 10,000 ft, coupled with the relatively older age of the volcano (compared with Mauna Loa below) indicate that it should support perhaps the greatest diversity of native arthropods among the parks in the network. This is especially true for the montane cloud forest area of Kipahulu Valley, which has been poorly surveyed for invertebrates but likely contains the highest diversity. HALE has a rich range of invertebrate habitat including coastal strand habitat, lowland rain forest, montane rain and cloud forests, montane bogs, subalpine grasslands and shrublands, montane dry forest remnants, and alpine cinder fields. HALE also supports both perennial and intermittent streams, pools, and subalpine lakes. There are approximately 15 threatened and endangered plant species that support small communities of obligately associated native arthropods. Several alien invertebrates have been identified as real or potential stressors in these communities, including ants, mosquitos, yellowjacket wasps, and slugs. HALE and its cooperators have been maintaining monitoring programs for argentine ants and the western yellowjacket wasp since the 1980s.

HAVO. Hawaii Volcanoes National Park on the island of Hawaii was the subject of an intensive inventory of terrestrial invertebrates under the US International Biological Program Island Ecosystems Integrated Research Program from 1971 to 1976. A field research station has also supported additional smaller invertebrate surveys and the park maintains an invertebrate specimen collection begun in the 1940's as part of its natural history museum. As a result of these activities, HAVO has a greater invertebrate specimen base than any other park in the network. However, only a small fraction of its more than 217,000 acres has been surveyed for terrestrial invertebrates. Like HALE, HAVO has a diverse range of habitats along often steep moisture and temperature gradients, including coastal strand habitat with anchialine pools, small patches of lowland wet and dry forest, seasonal submontane woodlands, detritus-based barren lava (neogeoaeolian habitat) and early successional vegetation on lava flows, montane wet, mesic and dry forests, subalpine forest and shrubland, a sparsely vegetated alpine and unvegetated aeolian zone. The greatest diversity of endemic invertebrates occurs in the montane wet and mesic forests in older kipukas, the East Rift Zone of Kilauea Volcano, and the disjunct Olaa Forest at and above the zone of contact between Kilauea and the southeast slope of Mauna Loa volcanoes. Many of the rare and endangered plant species in this area support small communities of host-plant associated endemic arthropods, and a number of species of concern are known from the park.

KAHO. Kaloko-Honokohau National Historical Park is a coastal park of approximately 470 ha (1,160 ac). Much of the vegetation is exotic, and this is reflected in the dominance of introduced insects. However, some native insects may still be found in the park, especially species with aquatic larval stages, which are less affected by ants. A survey of the insect fauna was carried out in 1992, and sporadic collections have been made since then. A more specific search for native insects associated with native plants in the park should be carried out. Anchialine pools and Hawaiian fishponds in the park support an endemic invertebrate fauna, including several types of shrimp, prawns, and the candidate endangered damselfly Megalagrion xanthomelas. These pools are vulnerable to invasion by introduced fish and human-caused damage and are strong candidates for monitoring. The park has an industrial area just upslope and residential and agricultural communities further up Hualalai mountain, all of which may contribute groundwater contaminants that may affect the invertebrate fauna of the pools.

KALA. Kalaupapa National Historical Park is a park of approximately 4,365 ha (10,778 ac) on the island of Molokai, established to preserve the cultural landscape of a Hansen's disease colony, along with scenic values of the area. The insect fauna is virtually unknown, but the variety of native vegetation found there, and collections from the surrounding area, suggests that it has the potential to harbor many interesting species. This is especially true of the Puu Alii region (designated a state Natural Area Reserve but within the authorized boundaries of KALA, and co-managed with the state of Hawaii), which contains a large area of montane wet forest. In addition to insects such as Campsicnemus and Drosophila flies, rare Partulina snails may be found there. Specialized cave-adapted species are found in lava tubes, including a recently-described planthopper. Other areas, including Waikolu, Waialeia, and Waihanau valleys, and dry forest and coastal strand communities on Kalaupapa penninsula, have probably been invaded by ants but may still harbor native insects, particularly stream-breeding species and bees (Hylaeus). Two candidate endangered Megalagrion damselfly species, M. pacificum and M. xanthomelas, are known from Waikolu stream. Aquatic species in the streams, including damselflies, and wet forest flies are particularly suited to long-term monitoring programs. As elsewhere, loss of habitat as a result of invasive plants and predation by introduced ants are the most important stressors on native invertebrates here.

NPSA. The National Park of American Samoa includes more than 3,640 ha (9,000 a) in four units on four islands of American Samoa. The legislation establishing the park recognized the importance of the Samoan tropical forests as one of the last remaining undisturbed paleotropical rain forests and as habitat of Pacific flying foxes. The insects are poorly known, but the intact rain forest suggests a diverse fauna is present. A diverse group of native land snails exists in Samoa, including the candidate endangered Eua zebrina and three species of concern, as well as several other rare species. It has been recommended that these be monitored for population declines.

PUHE. Puukohola Heiau National Historical Site is a 35-ha (86 a) coastal park on the island of Hawaii established to protect Hawaiian culture and historical sites. The era of Hawaiian inhabitation, specifically the period of heiau or temple construction (ca. 1790), is the target historical period. Natural vegetation has been largely replaced by alien vegetation, and many native species exist in the park only as plantings by park staff. PUHE has the most altered vegetation of the four Hawaii Island parks. As a result, it also has the fewest native species; in a 1992 survey, the only endemic species found were a predaceous bug and a moth able to feed on introduced grasses.

PUHO. Puuhonua o Honaunau National Historical Park is comprised of 74 ha (182 a) on the coast of Hawaii Island; it was established to protect Hawaiian culture and historical sites. The era of Hawaiian habitation is the target historical period. Natural vegetation has largely been replaced by alien species, but many Polynesian and indigenous species have been planted by Park staff near the Visitor Center. Native insect diversity is intermediate between that of KAHO and PUHE, consisting primarily of aquatic flies but also with a few moths and other species; the 1992 survey found 125 introduced species and 13 natives. As programs to control alien plants and restore native vegetation progress, the latter should be monitored periodically for recolonization by endemic insects.

USAR. The USS Arizona Memorial is a 4-ha (10-a) site in Pearl Harbor, island of Oahu, Hawaii. There are no terrestrial or non-marine aquatic invertebrate resources in this park unit.

WAPA. War in the Pacific National Historical Park is a park of approximately 800 ha (2,000 a) dispersed over seven units in the Territory of Guam, Mariana Islands. The enabling legislation states that the campaigns of the Pacific theater of WWII are to be commemorated and the natural and scenic values of Guam are to be conserved. WAPA supports limestone forest, savanna, and ravine or riverine forest, as well as disturbed areas of secondary vegetation. Guam supports an insect fauna of perhaps 2,000 species, with an endemicity rate of 45%. These include two candidate endangered butterfly species (one of which appears to be extirpated from the island), and an island-endemic species that has not been seen since 1916. Trading in butterflies may increase the threat to the candidate species. Much research has focused on introduced pests and biocontrol agents. The former have increased dramatically with the reduction in bird, lizard, and bat populations due to the alien brown tree snake. Invasive pests often arrive by way of Hawaii due to heavy traffic between the islands. The mosquito population increases dramatically during the wet season and after frequent typhoons, and can spread diseases such as malaria, dengue fever, and filariasis. Five land snails in the family Partulidae are historically known from Guam; one has not been recorded since 1946 and is considered extinct, and the other four are candidate endangered species. One of the latter has not been seen in several years and may have been extirpated from the island. Shells of some of these species are traded and harvesting may still be a concern.

Introduction

A. General Definition of Topic Area

Invertebrate monitoring includes monitoring of alien and native invertebrate species populations and monitoring of invertebrate communities. Population monitoring addresses changes in populations of incipient invasive species and alien invertebrates established in the parks, intentional introductions, key native species, and rare species including Species of Concern and candidate Endangered species. Community monitoring includes quantitative monitoring of invertebrate communities as well as vegetation mapping of the spatial distribution of plant communities. Community monitoring typically addresses alteration of species composition with changes in vegetation communities, ungulate disturbance, invasion of alien invertebrates, and recovery after alien species control and ecological restoration efforts.

B. Monitoring Goals.

A monitoring program will provide data for the following goals:

- An early warning system for managers about newly invasive invertebrate species, changes in established alien invertebrate populations and invertebrate communities, and loss of rare or key native species to help develop effective control and mitigation measures.
- Information about status and trends in invertebrate populations and communities to better understand them and develop strategies for alien species control and ecological restoration programs.
- Feedback to managers about effects of disturbance, alien species control, ecological restoration, and rare species management programs to help them manage adaptively.
- Assess effects of habitat fragmentation, develop strategies for conservation partnerships, and evaluate landscape level restoration attempts.
- Measure progress and meet reporting requirement of the performance management system, Endangered Species Act, and other Congressional requirements.

C. Role of Monitoring program.

The monitoring program will operate within an adaptive management feedback loop to help establish and evaluate alien species control, ecological restoration, and rare species recovery programs. Some monitoring activities will provide long-term monitoring apart from specific management treatments but much of it will be tied to management treatments.

Mandates to Consider

A. Park enabling legislation.

None of the Pacific National Parks have specific language regarding invertebrates. Lands now included in HAVO and HALE were established under the same legislation, which provides protection for “all timber, birds, mineral deposits, and natural curiosities or wonders” within the park. PUHE, PUHO and KAHO were established to protect Hawaiian cultural and historical sites, and the era of Hawaiian inhabitation is the model for the historical landscape. The legislation for KALA states that “natural features” are to be researched, preserved and maintained. ALKA legislation does not mention natural resources of the 175-mile historic trail. The enabling legislation of WAPA states that the campaigns of the Pacific theater of World War II are to be commemorated, and the natural and scenic values of Guam are to be conserved. Likewise, AMME was established on Saipan to honor those who died in the WWII Mariana Islands campaign, and no natural resources management is specified. The act establishing NPSA recognized the importance of the Park’s tropical forest as one of the last remaining undisturbed paleotropical forests and as habitat for Pacific flying foxes, and stated that the park should “preserve the ecological balance” of the forest.

B. Endangered Species Act.

The only listed endangered insect in the Pacific, Blackburn’s sphinx moth (Manduca blackburni), is not known to occur in any of the parks. Several candidate endangered species, including members of the genera Drosophila, Emperoptera (both flies), and Megalagrion (damselflies), and a large number of species of concern (SOCs) occur in or near HALE, HAVO, and KALA. SOC insects and the candidate endangered anchialine pool shrimp Metabetaeus lohena are present in KAHO. PUHE and PUHO are not known to contain any endangered or SOC invertebrates. The remaining parks have been poorly surveyed and are not known to contain any insect SOCs. Among snails, the candidate endangered Eua zebrina and Ostodes strigatus, and seven SOCs in the genera Diastole, Samoana, and Trochomorpha, are found in or near NPSA. One species of Partula and one Samoana, both candidates, are found on Guam in or near WAPA; a third Partula occurs in AMME. Four SOC tree snails in the genus Partulina are found in or near KALA.

C. NPS Management Policies.

The National Parks Omnibus Management Act (1998) defined the role of NPS as a conservation and science agency. Among the items it specifically mandated were the establishment of an inventory and monitoring program to obtain baseline information on natural resources, and the development of a broad, rigorous scientific research program. Resources management in HALE and HAVO has been primarily concerned with natural resource conservation and has expended considerable effort in protection and restoration of the native biota. Both parks also maintain active field research stations, operating under USGS-BRD, that perform research both inside and outside the parks. KAHO, KALA, PUHE, and PUHO have been primarily focused on cultural resources, but major programs to remove alien vegetation and restore native habitats have been undertaken or are underway at KAHO and KALA.

D. Local Controls and Regulations.

The State of Hawaii has legislation that allows for the listing of endangered species at the State level. To date, no invertebrates other than those recognized on Federal endangered species lists have been listed as threatened or endangered. The State of Hawaii also has injurious wildlife regulations that recognize some alien animals as harmful to agriculture or native animals and plants, and prohibits their introduction to new areas (State of Hawaii, 1997). Currently, all invertebrates on the injurious species list are molluscs.

Geographic Setting and Conceptual Models

A. Natural and Existing Vegetation

Native invertebrates are largely restricted to areas of predominantly native vegetation. Thus, their fate is intimately connected with the existence, diversity, and health of native plant communities. Many species of insects are host-specific, and may be extirpated even if their host plant persists at low population levels. This is especially true for groups such as Drosophila, moths, and planthoppers. They in turn are often the hosts of specialist predators and parasitoids, which follow their host into extinction. Among the Hawaii parks, HALE and HAVO have the greatest diversity of existing vegetation and the highest proportion of natural vegetation. HAVO has coastal strand vegetation, remnant lowland wet and dry forest, dry open woodlands, early successional vegetation on lava flows, montane rain forest, montane mesic forest, montane dry forest, subalpine forest and shrubland, and a sparsely vegetated alpine zone. HALE has coastal vegetation, highly disturbed lowland rain forest and mesic forest, intact lowland and montane rain and cloud forests, montane bogs, subalpine grasslands and shrublands, alpine aeolian cinder fields, montane dry forest remnants, and leeward mesic shrublands. HALE also supports both perennial and intermittent streams, pools and subalpine lakes. There are approximately 15 threatened and endangered plant species that support small communities of obligately associated native arthropods. KALA has coastal strand, loulu palm (Pritchardia) coastal forest, remnant lowland mesic forest, native vegetation on cliff faces, and lowland and montane wet forest. Natural vegetation of the three Kona historical parks (PUHE, KAHO, and PUHO) has been largely replaced except for coastal strand and wetland vegetation. AMME is covered by alien secondary vegetation except for a wetland and coastal mangroves. WAPA contains remnant limestone forest, savanna, and ravine or riverine forest, as well as disturbed areas of secondary vegetation. The four units of NPSA have vegetation ranging from coastal strand and littoral forest to Dysoxlum lowland rain forest, montane rain forest, and summit scrub dominated by ferns.

B. Natural Invertebrate Resources

1. Insects

Nearly all major insect groups contain large radiations in the Hawaiian Islands, with a total of over 5,000 endemic species. Some examples of groups with over 50 species include Campsicnemus, Drosophila, and Scaptomyza flies; Laupala and Trigonidium crickets; Kilauella and Ptycta barklice; Nesophrosyne and Nesosydne planthoppers; Blackburnia and Mecyclothorax beetles; Hylaeus bees; and Nesodynerus and Sierola wasps. HALE, HAVO, and KALA contain a high diversity of the groups mentioned above. Even without extensive systematic sampling, HAVO is known to contain about 70 species of Drosophila (including over 20 undescribed species), 40 species of Sierola, 30 species of Campsicnemus, and 20 species of Hylaeus. Different suites of species are found in different habitat types, often with a large number of congeneric sympatric species occupying distinct microhabitats. Moreover, the lack of competitors has frequently led to the evolution of globally unique characteristics in Hawaiian species. Eight of the 12 flightless species of long-legged flies in the world are from Hawaii (derived from two separate lineages); the only cleptoparasitic bees in the family Colletidae are five Hawaiian species; and several Drosophila species are among the largest in the world. Although relatively few colonists have reached the islands, those that did and speciated profusely in this tiny area often make up a large percentage of the world fauna (Lispocephala: over 100 out of 150; Sierola: 180 out of about 200; Colletidae: 60 out of about 700; Drosophilidae: about 500 out of 3300, with many more undescribed)

The greatest diversity of Hawaiian insects is in montane wet forest. Kipahulu Valley in HALE, Olaa forest in HAVO, and the Puu Alii area of KALA contain extensive areas of this type. It is the primary habitat of Campsicnemus and Drosophila flies, and other groups, including Hylaeus and Sierola, are most diverse there. Damselflies (Megalagrion) are also found in wet forest, breeding in small puddles on the ground or in water collecting in the leaf axils of plants. Montane mesic forest also supports a high diversity of native invertebrates. HAVO contains a uniquely diverse area of mesic forest, including at least one species of picture-wing Drosophila that is restricted to the area. Lava tubes – most abundant in HAVO but also found at PUHO, KALA, and possibly KAHO – harbor unique cave-adapted species, usually independently evolved from surface-dwelling ancestors at each cave complex (Hoch, 1999). Although coastal and lowland habitats have been highly altered by alien vegetation, invasive ants, and human disturbance, they still harbor unique species, particularly bees and damselflies. The rare bees Hylaeus anthracinus, H. longiceps, and H. hilaris are found at the nearby Moomomi TNC preserve (Daly, 2003), and probably also occur at KALA. Restoration of native coastal shrubland and forest is underway that may provide improved habitat for these species. The candidate endangered species Megalagrion pacificum and M. xanthomelas are found in lowland streams and pools at HALE and KAHO respectively, and both are found at KALA (Polhemus, 1994). Other aquatic species, especially flies, are also able to persist in such places where alien fish are absent, even where the surrounding vegetation and insect fauna is largely alien.

The insect fauna of Samoa does not contain highly diversified groups as in Hawaii, but does contain a number of endemic isolates or relicts that are only found in scattered disjunct distributions elsewhere. The fauna is not well known because recent entomological work has focused almost exclusively on agriculture, and collecting has historically been more intensive in western Samoa than American Samoa. NPSA is a high-priority candidate for a park invertebrate survey.

The island of Guam is estimated to hold about 2,000 of the 10,000 total insect species in Micronesia (Gressitt, 1954). Although many alien species are present, about 45% are thought to be endemic to the Marianas. The fauna includes 15 butterfly species, of which two are candidate endangered species. Another species has not been seen since the type collection in 1916 and is presumed extinct. Since WAPA has not been surveyed for insects, the insect diversity of the park itself is difficult to estimate. However, since the park is composed of multiple fragments that contain remnant native habitat, it is expected that it contains significant diversity of native insects.

2. Land Snails

Populations of native snails are threatened across the Pacific, particularly in Hawaii, largely due to widespread introduction of predators, including the snail Euglandina rosea and the flatworm Platydemus manokwari. Four rare species of Partulina have been found in or near the Puu Alii section of KALA, but none are currently known from the other parks in Hawaii. A few groups, such as succineids, are widespread and relatively common. NPSA still has a diverse snail fauna in all units of the park, and the islands of Ofu and Olosega are still free of Euglandina and predatory flatworms. Twenty-eight native species were found in a recent survey of NPSA, 23 of which were considered rare (Cowie, 1999). One of them, Eua zebrina, is a candidate endangered species. The land snail fauna of Guam has been similarly reduced, particularly the Partulidae. Three species of Partula are historically known from the island, but one is believed to be extinct, and the other two are very rare and listed as candidate endangered species. In a recent survey (Hopper, 1992), P. radiolata and the listed candidate Samoana fragilis were found in or near WAPA. A new population of one of the Partula species, P. gibba, was recently discovered at AMME (D. Minton, pers. comm.).

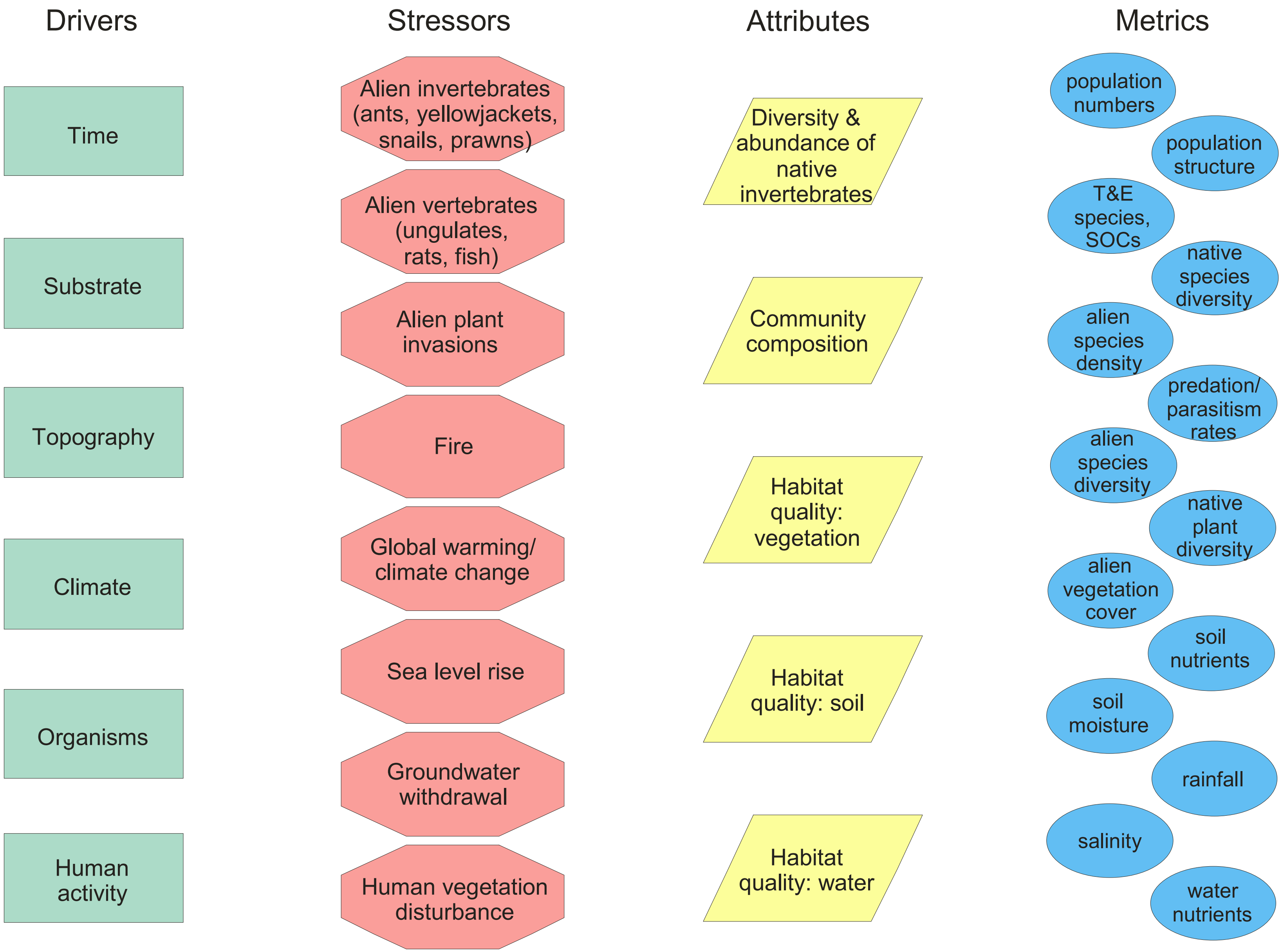
3. Anchialine Pools

Found in KAHO, PUHO, and HAVO. These brackish, tidal-influenced pools are home to a number of unique invertebrates, mainly crustaceans. Invasion by introduced mosquitofish (Poecillidae) can lead to greatly reduced numbers or extirpation of the native fauna. Anchialine pools at KAHO are the main breeding site for the candidate endangered Megalagrion xanthomelas there. The candidate endangered shrimp Metabetaeus lohena is also found in pools at KAHO, and other rare species may be found there when more intensive surveys are done. The pools of HAVO, last examined in 1989, are to be resurveyed in 2004.

Conceptual Model

The conceptual model for invertebrates is presented below. Stressors and natural drivers are listed with the attributes affected by them. Within the attributes are listed the impacts to the resources caused by the stressors. Metrics for use in monitoring the attributes are suggested. This is a highly generalized model covering all ecosystems; subset models will be constructed for individual islands and ecosystems emphasizing the particular forces at work in them.

Figure 1. Generalized conceptual model for invertebrates in Pacific Island ecosystems.



Local and Network-wide Issues

A. Detection & Control of Existing Invasive Invertebrate Species Threats.

All parks face threats from invasive species. HALE, HAVO, and NPSA are especially vulnerable because of their abundant and diverse native invertebrate faunas, high level of visitation by off-island tourists, and proximity to population and agriculture centers. A wide variety of invasive invertebrate pests are already established in the parks, affecting native invertebrates, vegetation, and cultural structures. In all parks, alien ants have had a major impact on native insects. It is largely because of ants that the parks of KAHO, PUHE, and PUHO lack native insects. This is the case even where native vegetation persists, and for native insects that can thrive in alien-dominated habitats. The lowlands of HALE, HAVO, and KALA are similarly affected. Establishment of the Argentine ant in montane areas of HALE and HAVO threatens insect populations in otherwise pristine native habitat. In WAPA, egg predation by introduced ants is a major factor in the decline of butterflies; in NPSA, alien ants also threaten the diverse native ant fauna of Samoa.

Another widespread problem is of parasitic wasps and flies, both intentionally and accidentally introduced. In the early years of biocontrol little regard was given to the effect of control agents on non-target species, or even on their actual role in controlling populations of the target pests. As a result, large numbers of generalist parasitoids were brought into the islands, and have caused dramatic changes in native insect populations. Many of the Hawaiian moths that were formerly enormously abundant, such as those in the genus Scotorythra, are now much less common, and species that were rare to begin with may now be extinct. In some areas or seasons parasitism rates may be close to 100%. The highly diverse native wasps (Nesodynerus) that prey on caterpillars have undergone a similar decline. Even the effectiveness of more recent, targeted biocontrol efforts for invasive plants has been sharply reduced by high rates of parasitism of the biocontrol agent. Although little monitoring of parasitoid populations and parasitism rates has been done, it is a serious concern that deserves greater attention.

Snails have been the victim of similarly misguided control efforts aimed at the giant African snail, a widespread exotic pest. The predatory snails Euglandina rosea and Gonaxis spp. have been widely introduced despite lack of evidence that they control the African snail, and have been implicated in the decimation of land snail populations in Hawaii, American Samoa, and Guam. In addition, the snail-feeding flatworm Platydemus manokwari has been introduced into Hawaii, Guam, and American Samoa. It has virtually eliminated both native and introduced snails (including even Euglandina) in many areas, and was probably a major contributor to the extinction of Partula salifana. Despite being listed as one of the 100 worst invasive species by IUCN, Platydemus is being widely promoted by the FAO for control of the African snail.

B. Detection & Control of Incipient Invasive Invertebrate Species Threats

Many threatening species have become established recently in the Parks or on the home islands of the Parks. Others are likely to be introduced to the islands, including some that are present on other islands of an archipelago. For example, Euglandina rosea has been introduced to the islands of Tutuila and Tau, but not Ofu and Olosega, where it would have a serious impact on rare native snails. Despite the large number of invasive ants already established, there are other known invasive species that could cause serious problems. Assessing the threat posed by incipient invasive species and detecting their presence are important monitoring functions for Pacific Island parks to insure proactive and cost-effective management.

C. Habitat Loss

The loss of plant habitat is the biggest indirect threat to invertebrates. Habitat loss can occur either by direct human destruction or modification, or by transformation as a result of alien plant invasion. Large areas exist in HALE, HAVO, KALA, and WAPA where the native plants have been almost entirely replaced by exotic vegetation; in KAHO, PUHE, and PUHO very little of the original plant cover remains. In general, most insect species are tied directly or indirectly to the vegetation native to the area. Relatively few native species are found in areas dominated by exotic plants. The majority of plant-feeding insect species, especially in groups that have radiated extensively in Hawaii, are specific to one or a few host plants. Many of their parasites and predators are specific as well. The result is that a reduction in plant diversity, even where the vegetation remains largely native, results in a dramatic decline in insect diversity, cascading across all functional groups. This is a frequent consequence of feral pig activity in Hawaiian forests, where the diverse species of trees, shrubs, and herbs in the understory are removed, leaving only the relatively few canopy species.

D. Human Harvest

Direct human taking is not a concern for most invertebrate species, but can have a major impact on those where it is. NPSA and WAPA both contain rare species such as snails and butterflies that are traded and sold; like other wildlife, the value of a specimen goes up as the species becomes closer to extinction. Huge numbers of snails were collected from Hawaii in the past (Hadfield, 1986). It is not known if collecting is affecting snail populations in or near any of the National Parks, but it is a concern. Coconut crabs are or have been heavily harvested for food on Guam and American Samoa, where subsistence harvesting is allowed in the park. As a result, the populations have declined and the age structure has been altered, with few large adults.

E. Restricted Populations and Stochastic Events

Many species have become restricted to small ranges, often in suboptimal habitat, due to the intrusions of invasive species, habitat destruction by humans, or loss of host plants. As a result, they are suceptible to extinction or extirpation by random, stochastic events. Typhoons on Guam are yearly events, but recent storms that damaged the forest canopy may have been the final blow to the snail Partula salifana, which was reduced to a tiny population by introduced predators and now appears to be extinct (D. Minton, pers. comm.). Species of Drosophila in HALE and HAVO are often restricted to a single host plant species, and require rotting plant material to breed. Regeneration of many plants was reduced or eliminated by feral ungulates (pigs and goats), such that some species have few individuals left within the parks. Even when ungulates are removed and plant regeneration begins again, the gap between the death of the older plants and maturity and death of the new generation can cause loss of the fly species dependent on them.

Monitoring programs and needs

A. ALKA

No monitoring. The path will run through KAHO and HAVO, but such areas will be handled under the auspices of the larger parks. Elsewhere the path of the trail(s) has not been defined and it is not known what management of natural resources will be undertaken.

B. AMME

No resource base inventory of invertebrates has been undertaken in AMME. The insect community of the native mangrove wetland, one of the last remaining in the Marianas, has not been examined and should be surveyed for odonates and other insect groups. The snail fauna is also not well known. However, a few individuals of the candidate endangered snail Partula gibba were recently discovered in the wetland. This group of snails is widespread in the Pacific Islands, but most species (including all five native to the Marianas) are now endangered or have been driven extinct due to alien predators. Discovery of them at AMME is significant because partulids were previously unknown for the area, and were not found on Saipan at all during the last survey of the island (Hopper, 1992). A stream in the park receives saline effluent from a desalinization plant and pollutants from a nearby town, affecting its suitability as habitat for invertebrates. Water quality monitoring for the stream should include the presence and abundance of stream-breeding insects and snails. The status of the alien ant community also deserves attention. Baseline transects established for vegetation monitoring in the wetland in the late 1980s could be used for timed-flight observations of dragonflies and other potentially sensitive native arthropods, as well as bait-station monitoring for ants and snail searches.

C. HALE.

Haleakala has been the subject of several inventories for invertebrates, including a preliminary resource base inventory of the crater district and lower Kipahulu Valley. Extensive insect collecting has also been carried out by park staff and a field research station has supported the work of other entomologists in the park. However, the invertebrate resources of much of the park remain poorly known, and much that is known is unpublished. Extensive elevational and moisture gradients on Haleakala, from sea level to greater than 3,000 m, coupled with the older age of the volcano (compared with Mauna Loa, below), indicate that it should support perhaps the greatest diversity of native arthropods among the parks in the network. This is especially true for the montane cloud forest area of Kipahulu Valley, which has been poorly surveyed for invertebrates but likely contains the highest diversity. Surveys of Palikea, Pipiwai, and Puaaluu Streams have been done, but these sampled insects only incidentally. The recently-acquired Kaapahu section also contains montane cloud forest as well as several streams that have not been extensively inventoried, except for a partial macrofauna inventory for lower Alelele Stream. Only one montane bog has been surveyed for insects (Loope, 1991). Several alien invertebrates have been identified as real or potential stressors in these communities, including ants, mosquitos, yellowjacket wasps, and slugs. HALE and its cooperators have been maintaining monitoring programs for argentine ants and the western yellowjacket wasp since the 1980's. Both of these species are highly damaging to native invertebrates and may also be controlled. Resource base inventories of invertebrates could be repeated as a form of long-term monitoring of terrestrial species. Recent inventories of yellow-faced bees (Daly, 2003) could also serve as the basis of a monitoring program for a diverse, yet rare, group of endemic pollinators. The submontane shrubland of HALE supports the only large population of native cleptoparasitic bees, but is threatened by invasion of Argentine ants (Cole, 1992). Monitoring of both native and alien species is needed for Kipahulu valley, and for pollinators and other insects associated with silverswords in Haleakala Crater.

D. HAVO

A large number of monitoring projects of varying extent are or have been carried out at HAVO. Long-term, continuous monitoring is being done on the invasive western yellowjacket and two-spotted leafhopper, and on mosquitoes as part of an avian disease project. Systematic surveys of select rare invertebrate groups have been conducted along transects in montane rainforests. Taxa were chosen that were taxonomically well-characterized and had been reported to show sensitivity to feral ungulate disturbance. These groups include Collembola (springtails) from the soil and litter invertebrate community; Drosophila (fruit flies) from the host-plant associated arthropods; and Megalagrion damselflies from the aquatic (and semi-terrestrial) insect fauna. Survey work was detailed enough to serve as a baseline for future monitoring efforts. Alien species of springtails and fruit flies have also been enumerated from survey samples and the relative abundance of native and alien members of these arthropod groups have been used as a gauge of recovery following the removal of feral pigs from Olaa Forest. Data on large endemic picture-wing Drosophila has been compared with survey data from the 1970s IBP surveys and more recent surveys in the 1980s. The results of this retrospective analysis indicates a loss of approximately 18% of the species from Olaa Forest. Similar declines have been noted for damselflies and as a consequence, species of both picture-wing Drosophila and Megalagrion damselflies have been proposed for listing under the US Endangered Species Act. Monitoring of Megalagrion damselflies is continuing in the Olaa Forest under the US Geological Survey Global Change Program, where these endemic damselflies are studied as indicators of hydrologic change in montane and coastal Hawaiian ecosystems. Other highly diverse or evolutionarily significant groups, including Nesodynerus and Sierola wasps, Lispocephala flies, and virtually all moths and barklice, are highly diverse but poorly known in the park. Many of these face a taxonomic impediment to an understanding of park resources, but a surmountable one. Soil and litter fauna, including alien slugs and ground beetles, have been monitored in conjunction with recent tests of rodenticides to control rats using compressed cereal-grain baits. These surveys can serve as the basis future monitoring of these poorly understood groups of invasive invertebrates. Formal monitoring is also underway for the western yellowjacket wasp, mosquitos, and the two-spotted leaf hopper. The wasp monitoring program is proportionally larger than its counterpart at HALE, but serves the same purpose for the timing and efficacy of alien wasp control programs using insecticidal baits. Two-spotted leafhopper monitoring was implemented following the discovery of its association with the decline of native ohia and alien faya tree centered in seasonal submontane habitats. Mosquito monitoring is being conducted in conjuction with a National Science Foundation Biocomplexity Project to understand vector relationships to avian disease and the decline of native forest birds. No effort has been devoted to monitoring the effects of fire, nor the impact of large-scale outplanting and habitat restoration programs, on invertebrate communities in the park. In the case of the former, large-scale changes in ant communities have been reported following fires in lowland areas. In contrast, habitat restoration programs should result in an increased dominance of native host-associated arthropod species. Moreover, some plants are highly dependent on insects. HAVO now contains the largest population of Kau silverswords, and is undertaking a large planting effort. However, no studies have been done on their pollination requirements or monitoring of potential pollinator visitation.

E. KAHO

Anchialine pools and Hawaiian fishponds in the park support an endemic invertebrate fauna, including several types of shrimp, prawns, and candidate endangered species of shrimp (Metabetaeus lohena) and damselfly (Megalagrion xanthomelas). Populations of M. xanthomelas breeding in the pools have been monitored for several years, but surveys for other important species have been sporadic. Many of the pools have been invaded by alien mosquitofish, with the result that native arthropods are largely absent from them. Anchialine pools are an important but vulnerable resource, and should be monitored. An extensive survey of the insect fauna in 1992 found relatively few native terrestrial arthropods aside from flies breeding in the pools. However, several native insects are dependent on the SOC plant Capparis sandwichiana as a host, and they should be examined for potential monitoring. A survey of the insect fauna was carried out in 1992, and sporadic collections have been made since then. A more specific search for native insects associated with native plants in the park should be carried out.

F. KALA

No invertebrate monitoring is currently ongoing. The insect fauna is largely unknown, but the variety of native vegetation found there suggest that it has the potential to harbor many interesting species. The unique lake in Kauhako Crater appears to contain endemic species, and needs to be examined more thoroughly. A new species of copepod and a genetically isolated population of shrimp (probably Palaeomon debilis) were found here in 1999. The Puu Alii section contains a large area of montane wet forest, which probably has a high diversity of native insects but has not been surveyed. Extensive, long-term collecting adjacent to the Puu Alii section and on the rim of Waikolu Valley has revealed a large assemblage of species that are probably almost all found within the park. An inventory of Waikolu and Waialeia streams has been done and should be repeated at regular intervals to monitor populations of aquatic insects and snails. Although water from Waikolu is partly diverted for human use, it is relatively pristine for much of its length and contains a diverse native invertebrate fauna (R. Englund, pers. comm.). Two candidate endangered Megalagrion damselfly species, M. pacificum and M. xanthomelas, are known from Waikolu stream. Monitoring programs for Megalagrion at HAVO and KAHO could serve as models for similar projects in KALA. Aquatic species in the streams, including damselflies, and wet forest flies are particularly suited to long-term monitoring programs. Four species of rare Partulina land snails are found in montane wet forest. The health of their populations needs to be established and monitored. Other areas, including Waikolu, Waialeia, and Waihanau valleys, and dry forest and coastal strand communities on Kalaupapa penninsula, have probably been invaded with ants but may still harbor native insects, particularly stream-breeding species and rare coastal bees (Hylaeus). Three species of the latter – including the only population of the extremely rare cleptoparasitic species H. hilaris – are found just to the west at Moomomi. Extensive plant restoration projects are currently underway in coastal and lowland areas of the park. Coincident with these efforts should be monitoring of plants for colonization by both native herbivores and alien pests.

G. NPSA

No invertebrate monitoring. A survey of land snails in 1998 found at least 42 native snail species. It documented several rare species as being present in the park, as well as predatory snails that have been instrumental in their decline (Cowie, 1999). The report recommended that regular monitoring be carried out annually, with more comprehensive surveys every five years. Coconut crabs, which are harvested for food, are a high priority for monitoring to understand population levels and trends. The mosquito-borne diseases filariasis and dengue fever are concerns, and may be subjects for control. Insect species have been catalogued but not identified for monitoring, and a survey of insects in the park is needed. The pristine rain forest within the park suggests a high diversity of native insects will be found there.

H. PUHE

No invertebrate monitoring. A survey of the park in 1992 found few native insects.

I. PUHO

No invertebrate monitoring. A survey of the park in 1992 found few native insects. Anchialine pools present in the park are smaller and shallower than those at KAHO and HAVO, and are less likely to harbor rare species. However, they have not been adequately investigated.

J. WAPA.

The insects of Guam have been surveyed (Gressitt, 1954) but, aside from agricultural pests, have not been well studied. Several invertebrate issues with high priority for monitoring are present: mosquitoes and disease transmission, outbreaks of insects due to elimination of predators, and endangered species of butterflies and land snails. Numerous species of mosquitoes are present: only 5 species are native, but over 30 others have been introduced. Among the introduced species are vectors of malaria, dengue fever, chikungunya fever, Japanese B encephalitis and filariasis, mosquito-borne diseases known to occur on Pacific islands. Native species are usually not efficient vectors of exotic pathogens, but can transmit Ross River disease, an introduced virus. Although these diseases are not currently a major problem, increases in mosquito populations following demise of vertebrate predators and periodic outbreaks of mosquitoes during the wet season make the potential for serious disease outbreaks high. Following the introduction of the brown tree snake, populations of insect-feeding birds, bats, and reptiles have been reduced or eliminated. This has led to an explosion in the insect and spider populations, with both agricultural and health consequences. The impact on community structure of native arthropods, and the balance of natives and aliens, is likely to be severe, with consequent effects on native vegetation. Native areas may also serve as potential source populations for agricultural pests. Six candidate endangered species are known from Guam: two butterflies and four land snails. One of the former, Vagrans egestina, was formerly common on Guam but has not been seen there since 1979. The other, Hypolimnas octucula mariannensis, is currently known from 10 populations on Guam (another species, Neptis guamensis, has not been seen since the type collection in 1916 and is presumed extinct). Both of these species are threatened by a number of factors, including habitat loss due to introduced deer, invasive plants, and development; introduced parasitoids; and unrestricted collecting for the butterfly trade. However, by far the most important factor is the presence of alien ants, which may take 99% of butterfly eggs at times. Two species of Partula land snails and one Samoana on Guam are candidate endangered species (another Partula, also a candidate, occurs in the Northern Mariana Islands; and a fourth, endemic to Guam, is believed to be extinct). The primary factor in reducing their numbers has been the introduction of alien predatory snails and flatworms in an effort to control another exotic, the giant African snail. With all three native species now occurring in small, highly restricted populations, they are highly vulnerable to development, land clearing, and stochastic events such as fire and typhoons. Identifying populations and monitoring population trends is a high priority.

Summary

A. Critical Invertebrate Resources

1. General

Extremely high diversity; candidate endangered species and species of concern.

2. ALKA

The invertebrate resources of the newly designated Ala Kahakai Trail have not been inventoried.

3. AMME

A wetland containing both native and non-native plant species is the most significant vegetation resource of this small park. The wetland containing mangroves is a type rare in the Northern Marianas and provides habitat for the candidate endangered snail Partula gibba.

4. HALE

The protected rain forests of Kipahulu Valley, a research natural area and scientific reserve, harbor a huge diversity of insects. This area has not been fully surveyed for its insect species. Subalpine shrubland protects large populations of native bees, including essential pollinators of silverswords. Aquatic-breeding species inhabit perennial streams.

5. HAVO

Extremely diverse insect fauna in wet and mesic forests, with many highly speciose taxa. Lava tubes support unique cave insects, many endemic to a single cave system. The summit of Mauna Loa is an aeolian ecosystem with flightless moths and predators feeding on wind-blown debris. Anchialine pools at the coast may host rare species. At least 3 candidate endangered species are present, with many SOCs.

6. KAHO

Coastal strand supports rare coastal populations of native bees. The park supports a large population of the SOC shrub Capparis sandwichiana, which hosts specialized endemic insects. Anchialine pools support a unique fauna including the candidate endangered damselfly Megalagrion xanthomelas and shrimp Metabetaeus lohena, and the SOC shrimp Halocaridina rubra.

7. KALA

The upper-elevation rain forests of Waikolu and Puu Alii, perennial and intermittent streams, diverse dry forest in Kauhako Crater, and coastal strand communities are important habitats. Wet forests in particular are likely to have a high diversity of insects, but have not been surveyed. Coastal areas probably support rare native bees. Waikolu stream supports populations of two candidate endangered Megalagrion damselfly species.

8. NPSA

Intact rain forests contain populations of SOC, candidate endangered, and other rare land snails. Forests and littoral and summit scrub probably also support a large insect fauna, and unusual species are known from the islands. Coconut crabs are in decline due to overharvesting.

9. PUHE

Native aquatic-breeding insects inhabit wetland areas.

10. PUHO.

Native pond-breeding insects and possibly SOC shrimp in anchialine pools.

11. USAR

No invertebrate resources.

12. WAPA

Candidate endangered butterfly (Hypolimnas octucula mariannensis) and two land snails are found in or near the park. Park contains limestone forest remnants, savanna vegetation recovering from fire, and riverine forests that may harbor species rare in more disturbed environments.

B. Stressors on Invertebrates

1. General/common stressors

Alien species invasions, especially ants; effects of nearby development; aquatic pollution; direct habitat (vegetation) destruction by humans and feral ungulates; indirect habitat destruction by invasion of exotic plants; inadequate systematic knowledge; vulnerability of small populations of rare species to stochastic events; and type of management in areas surrounding Parks including introduction of new species.

2. ALKA

Stressors are unknown at this time; surveys and evaluation of resources are necessary.

3. AMME

Water pollution, including effluent and runoff in the stream and dumping in the wetland; encroaching development from the adjacent town; predatory snails and flatworms.

4. HALE

Invasive social insect predators (Argentine ants, yellowjackets); visitor impacts in alpine zone; change in nutrient, soil, water, and fire regimes; decline or loss of rare host plants; habitat transformation by feral ungulates and invasive plants.

5. HAVO

Invasive social insect predators (Argentine ants, yellowjackets); decline or loss of rare host plants; habitat transformation by feral ungulates and invasive plants; change in nutrient, soil, water, and fire regimes; wildfire; lava flows and volcanic emissions.

6. KAHO

Development of coastal and upslope lands near the park; invasion by alien plants; groundwater withdrawal, pollution, and runoff; seawater pollution; alien fish; sea level rise.

7. KALA

Human impacts on offshore islands; invasive alien plants and animals (ants, yellowjackets, snails, flatworms); stream water diversion; fire.

8. NPSA

Expanding subsistence agriculture into forest; invasive alien plants and animals (feral pigs, rats, ants, snails, flatworms).

9. PUHE

Invasive alien plant species; ants.

10. PUHO

Incompatible development encroaching on park; invasive alien plants; ants.

11. USAR

No non-marine invertebrate resources.

12. WAPA

Wildfire and subsequent erosion, particularly in savanna vegetation; invasive ants, snails, and flatworms; adjacent incompatible development; invasive ungulates (feral pigs, Philippine deer) and alien plants; typhoons that repeatedly disturb vegetation cover, particularly in limestone forest.

C. Monitoring Needs

1. General

Trends in rare species populations; invasive species infestation limits and effects.

2. ALKA

Monitoring needs are currently unknown.

3. AMME

Wetland insect community monitoring; snail population monitoring.

4. HALE

Monitoring of indicator species in wet forest, bogs, and streams; insect pollinators of silversword and other rare plants; Argentine ant infestation; yellowjacket abundance and control effectiveness; long-term changes in diversity in rain forests, diverse mesic forests, and upper montane, subalpine, and alpine ecosystems.

5. HAVO

Survey of new Kahuku unit; indicator species in wet and mesic forests; insect pollinators of silversword and other rare plants; yellowjacket abundance and control effectiveness; long-term changes in diversity in rain forests, diverse mesic forests, and upper montane, subalpine, and alpine ecosystems; recolonization by natives and exotics following fire; recolonization of restored vegetation.

6. KAHO

Anchialine pool community; rare and endangered species (especially Megalagrion xanthomelas); invasive species in pools; recolonization in native plant restoration areas; associates (pollinators and obligate herbivores) of rare plants.

7. KALA

Recolonization of restored plant communities, including invasion by exotic pests; damselfly monitoring in Waikolu stream; inventory and monitoring of Kauhako Lake fauna.

8. NPSA

Community monitoring, including status of native and exotic species; native and predatory snail population trends; coconut crab abundance and demographics.

9. PUHE

Recolonization in native plant restoration areas.

10. PUHO

Recolonization in native plant restoration areas.

11. USAR

No invertebrate monitoring needs.

12. WAPA

Influence of vegetation change on insect and snail populations; population trends of rare butterfly species and native and predatory snails; coconut crab abundance and demographics.

D. Research Needs

Protocols based on previous monitoring of Drosophila, Megalagrion, snails, ants, and yellowjackets can be used as the basis for a range of future monitoring projects, including rare natives and invasive aliens. Systematic surveys of several areas (e.g. upper Kipahulu valley, Kaapahu, Kahuku, NPSA, and WAPA) need to be carried out to determine monitoring needs and priorities. Indicator species, and in some cases monitoring protocols for them, need to be determined for many ecosystems. In some cases, rapid identification of indicators and monitoring of their status can serve to track the health of the general fauna where long-term surveys are needed but cannot be done. Monitoring involving plant-insect interactions (recolonization of restored areas, plant limiting factors, pollination) are extremely important to both groups, and will be done in coordination with vegetation monitoring. Investigation of relationships between insects and plants, including the degree of dependence of one on the other, needs to be more thoroughly understood. A taxonomic impediment exists for some groups that are important for monitoring, and needs to be at least partially worked out.

Appendix A: Data Mining Sources

Still gathering information and data on this section.

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Appendix C: Workgroup Membership

Terrestrial Vertebrate Fauna Workgroup Overview

Charlotte Forbes Perry, Facilitator

Darcy Hu, Workgroup Lead

These materials are currently in DRAFT form (as of 3/5/04). The authors have been asked to share these reports for comment in March 2004. In several cases, authors have only had several weeks to work on these materials, and this may be evident in the content of the report. Accordingly, we hope that comments can focus on helping us ensure we have identified the breadth and significance of natural resource and ecological issues in the Pacific Island Network.

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Executive Summary

The terrestrial vertebrate fauna group is addressing native and alien vertebrate animal populations and communities found within parks. Native vertebrates that are likely to be of high concern for monitoring include rare species and groups; federally listed threatened or endangered species; animals with important functional roles in ecosystem processes such as pollination, seed dispersal, etc.; animals with special cultural significance; and animals that serve as indicators of natural or anthropogenic environmental change. Alien vertebrates of particular concern for monitoring include species parks are controlling (or want to control) due to their ability to reduce native biodiversity, species that pose specific threats to high priority native plants or animals, and species that pose identified or potential human health risks (i.e., rats as vectors of leptospirosis in freshwater sources, soil, campgrounds/campsites, picnic areas etc). Marine birds, water birds and shorebirds are also considered here.

This report's objectives are to identify and summarize existing knowledge and understanding of terrestrial vertebrate fauna, as well as to identify important information gaps. In conjunction with other working group reports, this information will be used to prioritize, design and construct a comprehensive ecological monitoring program for the networks' eleven parks.

The islands covered in this report are located in Micronesia in the western Pacific (WAPA, AMME), the main Hawaiian Islands in the central Pacific (ALKA, HALE, HAVO, KAHO, KALA, PUHE, PUHO, USAR), and American Samoa in the south central Pacific (NPSA). The native terrestrial vertebrate fauna in Pacific Island parks is quite depauperate when compared to the continental US or Asia or to continental islands. Native terrestrial vertebrates in Hawaii are confined to birds and the native bat. All other terrestrial vertebrates (i.e., herptofauna and other mammals) are alien. American Samoa has three native bats , the endemic Samoan starling and 24 resident land and fresh water birds, 20 resident seabirds, 7 skinks, 4 geckos, 1 snake, 2 sea turtles, 2 whales, dolphins, and 890 coral reef fishes (Peter Craig, personnal communication) Guam and Saipan reflect a more Indo-Pacific derivative, and thus, native terrestrial fauna in these parks include native birds, bats, and some species of reptiles.Smaller land areas and concomitantly smaller populations, plus high levels of endemism, make many threats potentially more serious in the Pacific islands than in mainland situations.

Legal mandates concerning terrestrial fauna include federal legislation for endangered species and migratory birds, NPS regulations, enabling Legislation, NPS Management Policies

(2001), Executive Orders, Director's Orders, and Hawaii State and local laws pertaining to wildlife.

[Insert here summary of section that describes what is known of terrestrial vertebrate fauna in each network park.]

A conceptual model is required by the NPS's Inventory and Monitoring program to facilitate communication between managers, scientists, stakeholders and the public during the monitoring planning process. At a workshop in March 2003, six ecosystem drivers were identified for a generalized, ahupua'a-based model of island ecosystems (see Conceptual Model chapter). These are: time, parent material, relief, climate, organisms, and human activity. The terrestrial fauna workgroup has adopted these major forces of ecosystem change in its model. Human activity, magnified and propelled by increases in human population size, has caused widespread and complex changes in all other drivers, including alteration of nutrient, water and meteorological cycles and of native organisms.

Stressors are physical, chemical or biological perturbations to a system resulting from the model drivers. We identified the following stressors: global climate change, sea level rise, biological invasions, pollution, water withdrawl, coastal changes, other disturbances or catastrophes (tsunami, fire, wholesale conversion or loss of vegetation such as from deforestation or conversion to agricultural use), habitat restoration, and human harvest.

We identified the following broad ecosystem responses to stressors: changes in species diversity; habitat loss; and changes to ecosystem structure, composition and/or processes. Attributes, measurable features or processes that provide insight into the state of the system, were next identified. These are: abundance of targeted alien and native species, including culturally significant species; population counts; variability of populations over time; diversity indices; habitat use patterns; reproductive parameters such as clutch size, hatching success, juvenile mortality; demography; food habits, and nighttime fallout of seabirds and possibly other nocturnal animals.

Lastly, we considered desired future conditions. With respect to terrestrial vertebrates, our goals are: alien species control or eradication for the most disruptive species, unaltered natural ecosystems (where they remain); restoration of extirpated native species; prevention of additional alien species establishments; increased knowledge of our resources, including basic species inventories in some parks; adaptive monitoring and management approaches to give us the flexibility to evaluate and change our techniques based on immediate feedback; and defensible data, including sound database design, documentation and archiving; and the use of appropriate monitoring design and data collection and analysis techniques to answer the questions posed.

Stressors identified in the conceptual model will have differing local and park effects on terrestrial fauna throughout the network. While our assessment of these effects is not exhaustive, we have attempted to anticipate the most serious impacts, particularly to native fauna.

Global climate change and associated severe weather events could change sea surface temperatures, impacting food supply for marine birds at HALE, HAVO, NPSA, and possibly at KAHO, PUHO, and WAPA. Severe weather events such as storms and floods during the breeding season particularly can impact ground and open-cup nesting birds in HALE, HAVO, KAHO, KALA, NPSA, and possibly WAPA. [There are many other potential impacts of this on vertebrates, and we have not tapped the literature here. Need to find a review paper.]

Sea level rise may result in loss of wetland and shoreline habitat for water birds at KAHO, habitas adjacent to ALKA and wetland birds at AMME. Migratory shorebirds, which currently use shorelines in all network parks, may lose feeding and roosting habitat. Shoreline-nesting seabirds at KAHO and possibly KALA, could lose nesting habitat. Sea turtles may lose nesting and/or basking habitat at HAVO, NPSA, HALE?, KALA?, KAHO, ALKA?, and PUHO. Monk seal pupping beaches may be lost at KALA.

Biological invasions include impacts of depredation, competition, disease, and displacement of food or other necessary habitat components for native vertebrates. Note: we took a resource perspective here, and thus, discuss impacts on native vertebrates regardless of the source of the impact. We did not cover specific effects of alien terrestrial vertebrates except where they impacted native terrestrial vertebrates. We expect the relevant workgroups will address impacts of alien terrestrial vertebrates on their respective resources.

Predatory invasive species. Rats and feral cats are probably the two most serious predatory threats to native avifauna shared by all network parks. In addition, there are well-established populations of mongooses on most of the Hawaiian islands and brown tree snakes on Guam and Saipan. Feral pigs are present in most Hawaii parks, as well as in NPSA and WAPA, and prey on ground nesting birds, eggs and chicks. Loose dogs pose occasional threats to wildlife at all (?) parks. Ants may threaten some native vertebrates, although impacts are not well documented (ask Ellen and LLL). All parks with native birds and reptiles are at risk from the potential establishment of the brown tree snake, with the nightingale reed warbler at AMME probably at highest risk. Impacts of predators on native bats are unknown in Hawaii. Any threats known to fruit bats in American Samoa?

Competition from invasive species. Competition has been implied or suggested at HALE by (Loope and Medeiros' paper on game birds cited in Kalij proposal) and Scott et al. for some alien Hawaiian forest birds such as the Japanese White-eye (CITE and check this).

Facilitating spread of diseases or pathogens. Mosquitoes and alien birds are responsible for the establishment and spread of avian diseases including malaria and pox in Hawaii. Feral pigs create additional mosquito breeding sites. Avian disease may have caused or contributed to the extinction of several endemic Hawaiian birds, and currently it threatens or limits many surviving species in HAVO, HALE, and possibly KALA. The role of avian disease in Samoa is a topic of current research (get additional info from LaPointe and Atkinson). Imported alien birds and possibly other animals are potential sources of new diseases. We have found no information on the impact of disease on surviving Guam and Saipan vertebrates.

Impacts of aliens on important habitat components. HAVO, HALE, KALA, NPSA WAPA and ALKA all have habitat that has been degraded by feral ungulates. Impacts of rats on native plant communities, although documented at HAVO in recent broadcast toxicant work (anywhere else is this documented?), probably affects all parks except USAR. However, we have found little information on the effect of these impacts on native vertebrates. Invasive alien plants in appear to have displaced native Nene food plants.

Pollution. AMME wetland, habitat for endangered Nightingale Reed Warbler, is threatened by water quality degradation. KAHO, PUHO and PUHE wetland habitats, used by endemic water birds and migratory species, are threatened by pollution from upslope or adjacent harbors. Any impacts at NPSA?

Water withdrawl. PUHE wetland may be threatened by upslope dewatering. The drop in the watertable due to upslope water withdrawl may impact endemic water birds and some shorebirds. Are there wetland areas that are drying up at KAHO possibly due to drop in watertable? Any impacts at WAPA?

Coastal changes. Increased human use disturbs shorebirds, basking and nesting turtles, and basking monk seals within parks. Shorelines outside parks are often heavily used and impacted by pets and lights. Thus, the more protected confines of the national parks may become increasingly important refugia for these animals.

Other disturbances or catastrophes (tsunami, fire, vegetative changes, urban encroachment). These large-scale, often sudden changes have caused loss of habitat for Bulwer's petrels at HAVO (subsidence associated with a tsunami), and loss of forest for native birds from fire (HAVO, HALE, WAPA?). Adjacent deforestation outside HAVO (other parks?) has further reduced forest bird habitat. Loss or fragmentation of less disturbed buffer zones outside all parks has accelerated the invasion of alien plants and predators.

Habitat restoration. Wetland habitat restoration to aid recovery of endangered Hawaiian water birds is in the planning stages at KAHO. Other habitat restoration work has been aimed primarily at native plant communities, and impacts on native terrestrial vertebrates have not been documented. The exception is native forest bird monitoring in recovering forest at HALE. Fences built to exclude feral ungulates have caught seabirds and bats at HALE and HAVO.

Human harvest. Both species of fruit bats at NPSA are harvested for subsistence; also Samoan doves (which species?).

See RMPs for additional park-specific issues

We summarized existing or on-going monitoring terrestrial vertebrate programs and partners identified by network parks. HALE reported the most extensive previous or on-going monitoring, including both direct monitoring of vertebrates and habitat monitoring. It also has an extensive partner list. HAVO, KAHO, KALA, NPSA and PUHO were intermediate; and ALKA and AMME, PUHE have no reported monitoring programs for terrestrial vertebrates or their habitats.

Terrestrial vertebrate monitoring needs identified by network parks focus on rare or listed species and those with cultural significance. Stressors identified by parks fell into the following categories: invasive aliens and biodiversity loss, climate change (including sea level rise), lava flows, and fire or altered fire regimes.

Identified information needs include editing and clean-up of the NPSpecies (inventory) database for all parks. Additionally, ALKA, AMME and WAPA need baseline inventories of their vertebrate terrestrial fauna.

Introduction

A. Definition of Topic Area

The vertebrate fauna group addresses native and alien vertebrate animal populations and communities found within parks. Native vertebrates that are likely to be of high concern for monitoring include rare species and groups; federally listed threatened or endangered species; animals with important functional roles in ecosystem processes such as pollination, seed dispersal, etc.; animals with special cultural significance; and animals that serve as indicators of threats to, or declines in, communities or ecosystems. Alien vertebrates of particular concern for monitoring include species parks are controlling (or want to control) due to their ability to reduce native biodiversity, species that pose specific threats to high priority native plants or animals, and species that pose identified or potential human health risks (i.e., rats as vectors of leptospirosis in freshwater sources, soil, campgrounds/campsites, picnic areas etc). We will not consider marine vertebrate fauna; nor will we consider freshwater aquatic animals, as both of these are covered by their respective workgroups. Exceptions are marine birds, whose colonies we will address, and to some extent water birds and shorebirds (probably more of a habitat perspective for this group)

B. Monitoring Goals

The report's objectives are to identify and summarize existing knowledge and understanding of terrestrial vertebrate fauna, as well as important information gaps. In conjunction with other working group reports, this information ultimately will be used to prioritize, design and construct a comprehensive ecological monitoring program for the networks' 11 parks. Terrestrial vertebrates could be included in the network's monitoring based on their roles as important components of ecosystems, indicators of broader natural or anthropogenic environmental change, or as keystones in native ecosystems.

C. Regions Used

The islands covered in this report are located in Micronesia in the western Pacific (WAPA, AMME), the main Hawaiian Islands in the central Pacific (ALKA, HALE, HAVO, KAHO, KALA, PUHE, PUHO, USAR), and American Samoa in the south central Pacific (NPSA).

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Smaller land areas and concomitantly smaller populations, plus high levels of endemism, make many threats potentially more serious in the Pacific islands than in mainland situations. E.g., avian diseases such as malaria that are naturally part of US mainland ecosystems are alien in Hawaii and possibly American Samoa. In Hawaii, avian disease has been devastating to native birds. Thus, incipient or potential threats also must be evaluated with the fragility of remote island fauna in mind. West Nile Virus is not expected to jeopardize many mainland species, but could have dire consequences for native species in Hawaii and other Pacific islands. Additionally, there may be distinct cultural affiliations between Hawaiian and Pacific Islanders and their native wildlife, and perhaps also some early vertebrate introductions.

Mandate(s) to consider

Information on Legislation and Mandates was located at website www.nature.nps.gov/im/units/nw31/pacn_policy.htm Summary of Legislation , National Park Service Policy and Guidance relevant to Development and Implementation of Natural Resources Monitoring in National Parks.

A. Inventory & Monitoring program (Natural Resource Challenge)

B. Endangered Species Act

Endangered Species Act of 1973 (administrators of the ESA: U.S. Fish and Wildlife Service and National Marine Fisheries Service). Purposes for the Endangered Species Act include; ecosystems upon which endangered and threatened species depend on may be conserved, all federal departments and agencies shall seek to conserve endangered and threatened species, and each federal agency shall insure that any action authorized , funded , or carried out by such agency is not likely to jeopardize the continued existence of any endangered or threatened species. Theses actions are primarily carried out via endangered species permits for activities that directly involve listed species; section 7 consultations for actions not covered under an endangered species permit that may affect listed species; and recovery plans, which NPS should strive to carry out applicable portions whenever possible.

C. Migratory Bird Treaty Act (administered by US Fish and Wildlife Service)

Unless permitted by regulations, the Act provides that it is unlawful to pursue, hunt, take, capture or kill; attempt to take, capture or kill; possess, offer to or sell, barter, purchase, deliver or cause to be shipped, exported, imported, transported, carried or received any migratory bird, part, nest, egg or product, manufactured or not. Subject to limitations in the Act, the Secretary of the Interior (Secretary) may adopt regulations determining the extent to which, if at all, hunting, taking, capturing, killing, possessing, selling, purchasing, shipping, transporting or exporting of any migratory bird, part, nest or egg will be allowed, having regard for temperature zones, distribution, abundance, economic value, breeding habits and migratory flight patterns.

D. NPS regulations

50CFR17: Endangered and Threatened Wildlife and Plants

E. Park Enabling Legislation (NPS)
This resource will be researched at a later date and incorporated into this report.

F. NPS Management Policies 2001-

- Restoration of Natural Systems 4.1.5. Re-establish natural functions and processes, biological and physical components and biological community structure. Examples include removal of exotic species, removal contaminants and non-historic structures, and restoration of native plants and animals.

- Plant and Animal Population Management Principles 4.4.1.1. Parks should work with partners to manage species that cross park boundaries or are also found outside parks.

- Management of Native Plants and Animals 4.4.2. Specifies when intervention is permissible to maintain native species. Examples include when a population occurs in an unnaturally high or low concentration as a result of human influences and it is not possible to mitigate the effects of the human influences; to protect rare, threatened , or endangered species; and where intervention meets specific park management objectives.

- Restoration of Native Plant and Animal Species 4.4.2.2. Specifies when to restore and limits highly manipulative activities for restoration.

- Management of Threatened or Endangered Plants and Animals 4.4.2.3. The NPS will survey for , protect, and strive to recover all species native to the national park system units that are isted under the Endangered Species Act and fully meet obligations under the NPS Organic Act.

- Maintenance of Altered Plant Communities 4.4.2.5. Limits and prohibits the use of exotic species to maintain Threatened and Endangered Species.

- Removal of Exotic Species Already Present 4.4.4.2. Prioritizes management and eradication of exotic species already present within a park.

- Biotic Cultural Resources 5.3.5.2.5. Management of biological resources with cultural significance.

- NPS-supported Studies 8.11.2. Inventory, monitoring, research studies to support management needs and objectives.

- Natural Resource Management Guidelines: Native Animal Management, Hunting and Trapping, Subsistence and other Traditional Uses- these resources will be researched at a later date and incorporated into this report.

- Park-specific Resource Management Plans-these resources will be researched at a later date and incorporated into this report.

G. Executive Orders (NPS)

Executive Order 13112: Invasive Species/ Exotic Species: prevent the introduction of invasive species, detect and respond rapidly to and control population in cost effective and environmentally sound manner, monitor aliens species populations, provide restoration of native species and habitat conditions in ecosystems that have been invaded. Conduct research on invasive species and develop techniques to prevent introductions and sound control of invasive species, promote public education on invasive species and means to address them.

Executive Order 11990: Protection of Wetlands ; requires all federal agencies to "minimize the destruction, loss, or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands". Unless no practical alternative exists, federal agencies must avoid any activities that have the potential to adversely affect wetland ecosystem integrity. NPS guidance pertaining to this Executive Order is stated in Floodplain and Wetland Protection Guidelines (National Park Service, 1980).

H. Director's Orders (NPS)

Director's Order #77-1: Wetland Protection: the purpose of this Director's order is to establish National Park Service Policies, requirements, and standards for implementing Executive Order 11990: Protection of Wetlands, to avoid to the extent possible the long and short term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or indirect support of new construction in wetlands wherever there is a practical alternative.

I. Hawaii State and any other local laws pertaining to wildlife

Hawaii Tropical Forest Recovery Act (1992): USDA & USFS. Authorizes Sec. of Agriculture and US Forest Service to establish biological control agents for non-native species. Creates task force to develop action plan to: "promote public awareness of the harm caused by introduced species" develop recommendations on "the benefits of fencing or other management activities for the protection of Hawaii's native plants and animals from non-native species, including the identification and priorities for the areas where these activities are appropriate

Hawaii State Revised Statues; Title 12, Chapter 195D-1 thru 5 (Administered by State of Hawaii, Department of Land and Natural Resources)

Except as permitted by Department rules, it is unlawful to take, possess, transport, export, process, sell, offer for sale, or ship a species of aquatic life, wildlife, or land plants in need of conservation (12-195D-3).

The Department may determine an indigenous species to be endangered or threatened because of any of these factors: the present or threatened destruction, modification, or curtailment of its habitat or range; over utilization for commercial, sporting, scientific, educational, or other purposes; disease or predation; inadequacy of existing regulatory mechanisms; or other natural or manmade factors affecting its continued existence within Hawaii (12-195D-4).

The Department shall conduct research on indigenous aquatic life, wildlife, and land plants, and on endangered species and their ecosystems, and shall utilize the land acquisition and other authority to carry out programs for the conservation, management, and protection of the species and their associated ecosystems. The Department is also authorized to acquire by purchase, donation or otherwise lands or interests therein needed to carry out conservation programs. The Governor's office shall review other programs administered by the Department and, to the extent practicable, utilize those programs in furtherance of the conservation purposes. The Governor or the Governor's representative shall also encourage other state and federal agencies to do the same by carrying out programs for the protection of endangered species and by taking action to insure that actions authorized, funded or carried out by them do not jeopardize the continued existence of the endangered species (12-195D-5).

In carrying out the programs authorized by section 195D, the Department may enter into agreements with federal agencies and counties for administration and management of areas established under 195D, or utilized for conserving, managing, enhancing, or protecting indigenous aquatic life, wildlife, land plants and endangered species. Priority shall be given to conservation and protection of endangered species and their ecosystems, whose extinction within the state would imperil or terminate, respectively, their existence in the world. The Department may permit taking, possession, transportation, or exportation of an indigenous endangered species for scientific purposes and for propagation in captivity for preservation purposes. The Department shall initiate amendments to the conservation district boundaries consistent with section 205-4 in order to include high quality native forests and habitat of rare native species of flora and fauna within the conservation district. The Department may seek assistance from appropriate public, private and nonprofit agencies and may employ consultants (12-195D-5.1).

J. CNMI

The CNMI Division of Fish and Wildlife is mandated by local law (Public law 2-51) to establishclear and uniform regulations governing hunting, fishing, conservation of fish and wildlife, and endangered species. Fish and Wildlife regulations are developed in order to conserve and preserve our Wildlife resources and their habitat. The regulations establish huntung and fishing seasons, legal and illegal equipment, declare endangered species, and determine sensitive habitat. See website www.dfw.gov.mp/interest.htm for details.

Local Laws pertaining to Wildlife for American Samoa, Saipan, and Guam will be further researched at a later date and incorporated into this report.

[I would like to insert here a section that describes what is known of terrestrial vertebrate fauna in each network park.]

Conceptual Model

The major components of the conceptual model for terrestrial vertebrates are outlined in Figure 1 (at the end of this report).

A. Drivers

- Time
- Parent material
- Relief
- Climate
- Organisms
- Human Activity

These major forces of ecosystem change were broadly categorized by Jenny (19??) and Vitousek (1995). Human activity, magnified and propelled by increases in human population size, has caused widespread and complex changes in all other drivers, including alteration of nutrient, water and meteorological cycles and of native organisms.

B. Stressors

1. Global Climate Change

The change in climate patterns over various time scales may have a variety of effects on existing ecosystems and their components. Among these are increased frequency and severity of weather catastrophes such as droughts, floods, hurricanes, and ENSO events. One or a series of these severe events can cause precipitous declines, particularly in already-small populations.

2. Sea Level Rise

Although also a result of global climate change, this is listed separately due to its somewhat distinct impact on island ecosystems.

3. Biological Invasions

Alien species invasions can impact native animals by predation; competition; facilitating the introduction of alien diseases and parasites; and displacing food supply, roost sites or other important habitat components. Invasive species may be even more damaging to native species and ecosystems on a global scale than the loss and degradation of habitats.

4. Pollution

Pollution from nearby harbors or upslope areas may degrade waterbird and migratory bird habitat. Species potentially affected include the endangered Nightingale Reed Warbler and Hawaiian water birds. Are there examples of air pollution with impacts on terrestrial verts in the network?

5. Water withdrawl

Causes reduction and degradation of wetland and estuarine habitat, and could change soil moisture, and thus, vegetative cover.

6. Coastal changes

Include construction or mining that alter natural beach regimes, as well as encroaching urbanization or heavy use of areas by humans.

7. Other disturbances

Include tsunami, fire, wholesale conversion or loss of vegetation (such as from deforestation or conversion to agricultural use).

8. Habitat restoration

Includes forest, wetland, and grassland habitats, and potentially other habitat types within the network. Also includes community "rehabilitation," which attempts to create somewhat novel habitats using native species adapted to an alien disturbance regime (e.g., fire) (CITE tim & rhonda—tech rpts?)

9. Human harvest

C. Ecosystem Responses

Changes in species diversity. This includes both of native (including threatened, endangered and rare), alien, and culturally significant species. This also includes the total loss (extinction or extirpation) of species, and changes in genetic diversity.

Habitat Loss. Rises in sea level may result in the loss of wetland habitat for water birds and migratory birds, and loss of nesting habitat for shoreline nesting seabirds.

Human encroachment may make coastlines uninhabitable for animals sensitive to human disturbance (nesting turtles, monk seals, some birds) or human commensal animals such as rats, feral cats, and dogs.

It is unclear what effect shifts in temperature, rainfall, or weather catastrophes could have on the Hawaiian Hoary bat, for little is known about the species. It is important to continue to gather information on the basic biology of bats, status of existing populations, and trends in number over time.Species that exhibit diurnal or seasonal changes in habitat use may lose a component of their habitat.

Changes in ecosystem structure, composition and processes. This response encompasses various forms of habitat degradation. For some species, these changes will be tolerable; for others, they will not be. Invasion of alien, fire-adapted grasses has changed the fire regime, thus further altering plant composition, and possibly nutrient cycling, in low and mid-elevation grasslands at HAVO, HALE and WAPA. Fauna impacted by these changes include Nene and potentially any native invertebrates still present. Decline of dominant tree species in forest habitat through fire, disease or selective harvest may affect birds and bats. Composition and processes (important functional roles for these organisms) - both species of fruit bats at NPSA are harvested for subsistence; also Samoan doves (there is a story about the dove according to Peter Craig; contacted my Samoan friend Tavita for clarification but no info yet -cfp). Loss of native food plants and/or nutrient cycles impact food plant availability and quality for Nene. Fragmentation of habitat (e.g., from agricultural encroachment in American Samoa). Are affects of fragmentation on birds, bats, alien plant invasions known? Sea surface temperature changes may impact the food supply for marine birds.

D. Measurable Attributes

Change in abundance of selected native and alien species. Changes in abundance of targeted alien and native species, including culturally significant species. Culturally important species include Hawaiian aumakua or family deities such as Pueo (HAVO, HALE, KAHO), Io (HAVO, PUHO), gecko or mo`o (probably all parks) as well as sharks (PUHE, KALA?); any other examples from Guam, Saipan or American Samoa?. Seabirds were formerly a food source mentioned in many historic accounts; Hawaiian honeycreepers were harvested for feathers (stories of bird catchers), and Nënë were used as watch dogs. These latter examples may have occurred and ended early enough that few modern cultural ties to these animals and practices now exist. Other targeted species could include highly invasive aliens being controlled by parks, threatened or endangered native species, more common native species that serve as indicators of system change, or keystone species that support native systems.

Population Counts: For threatened, endangered, rare or indicator/keystone species, population counts or estimates may be possible and desirable. Changes in variability of populations over time may be indicative of negative ecosystem responses. However, in all cases, changes must be distinguishable from any “normal” population fluctuations.

Diversity indices. Use of one or more of these may be indicative of system changes. (Has this technique been used as a monitoring tool here before? When would it be most appropriate?) Genetic diversity may be of concern for small populations and can be measured if tissue samples are available. Non-invasive sampling (e.g., analysis of scat samples) may also be possible if techniques are developed further.

Changes in habitat use patterns. Native species may shift habitats in response to aliens, climate change, or habitat degradation. In some cases, species remain in marginal habitat only. Presence/absence monitoring may be appropriate here in some cases.

Changes in reproductive parameters such as clutch size, hatching success, juvenile mortality.

Changes in demography could serve as an early warning of reproductive failure, particularly in long-lived species with lower reproductive rates. However, it must be possible to distinguish ages or age classes.

Changes in food habits. Animals may switch to different food sources as a result of habitat changes or invasive species’ impacts on their food supply.

Changes in nighttime fallout of seabirds and possibly other nocturnal animals, is indicative both of population status in colony areas (e.g., Kauai fallout data) and of problems with light pollution.

E. Desired Future Conditions

Alien species control or eradication for the most disruptive species, perhaps including rodents, ungulates, some invertebrates, and the brown tree snake.

Natural ecosystems remain unaltered: there are probably few instances where ecosystems are not yet altered. Are there examples yet from Samoa? Ola`a at HAVO? Or pit craters? Kipahulu in HALE? Puu Alii in KALA? Anywhere terrestrial in WAPA?

Restoration of extirpated native species implies habitat restoration and resolution of limiting factors such as depredation by alien species or disease-related mortality and morbidity.

Prevention of other alien species establishments. How would one measure or assess this? Check with LLL.

Increased knowledge base: we need basic vertebrate inventories for WAPA, AMME, and parts of NPSA. We also know very little about the endangered Hawaiian Hoary Bat, and about nesting locations of Newell's Shearwaters and Band-rumped Storm Petrels.

Adaptive monitoring and management approaches will give us the flexibility to evaluate and change our techniques based on immediate feedback. The desired result is a monitoring program that is reflective of park management needs and can recognize and adapt to new challenges.

Defensible data: sound database design, documentation and archiving; use of appropriate monitoring design and data collection and analysis techniques to answer the questions posed.

Local & Park Issues

Local & Park Issues with management, scientific, regional or national significance (stressors related to network parks; did not (yet) address ecosystem responses from the conceptual model)

A. Global climate change and associated severe weather events.

Sea surface temperature changes may impact food supply for marine birds at HALE, HAVO, NPSA, and possibly at KAHO, PUHO, and WAPA where seabird presence is not well documented. (cite hodges for decline in RS during El Nino.)

Severe weather events such as storms and floods during the breeding season particularly can impact ground (Nene, Pueo, stilt) and open-cup nesting birds (forest birds). Parks with these resources are: HALE, HAVO, KAHO, KALA, NPSA, ALKA and possibly WAPA.

WAPA has concerns with weather patterns and rainfall associated with El Nino affecting terrestrial fauna. There are many other potential impacts of this on vertebrates, and I have not tapped the literature here. Need to find a review paper—ask D foote?

B. Sea level rise.

Sea level rise may result in loss of wetland and shoreline habitat for water birds at KAHO, habitats adjacent to ALKA, and wetland birds (nightingale reed warbler) at AMME. Migratory shorebirds, which currently use shorelines in all network parks, may lose feeding and roosting habitat. WAPA (small seeps and springs, near cliff bottoms in Asan unit) associated with wetlands are of concern. Shoreline-nesting seabirds, i.e., shearwaters at KAHO and possibly KALA, could lose nesting habitat. Sea turtles may lose habitat: nesting beaches for hawksbill turtles at HAVO and green sea turtles at NPSA; loss of basking beaches for green sea turtles at HAVO, HALE?, KALA?, KAHO, NPSA?, and PUHO. Monk seal pupping beaches may be lost at KALA if the shallow, protected pools used by young pups are submerged.

C. Biological invasions

(Depredation, competition, disease, displacing food or other necessary habitat components of native vertebrates. Note: we do not cover specific effects of alien terrestrial vertebrates except those related to native terrestrial vertebrates. We expect the relevant workgroups will address impacts of alien verts on their resp resources.)

1. Predatory invasive species

Rats and feral cats are probably the two most serious predatory threats to native fauna shared by all network parks. In addition, there are well established populations of mongooses on most of the Hawaiian islands and brown tree snakes on Guam, and possibly and incipient population on Saipan (CITE). Feral pigs are present in most Hawaii parks, as well as in NPSA and WAPA, and prey on ground nesting birds, eggs and chicks. Loose dogs pose occasional threats to wildlife at all (?) parks. Ants may threaten some native vertebrates, although impacts are not well documented (ask Ellen and LLL). AMME has concerns with threats from dogs, cats, rats and the Brown tree snake which has also been sighted in Saipan.

Water birds and ground nesting seabirds at KAHO are threatened by mongooses, rats and feral cats. Hawaiian Petrels, Nene and forest birds at HALE and HAVO also are impacted by these same predators. Rat impacts have been documented on `Elepai`o at HAVO (Sheema and Sarr unpubl.). Rats and feral cats may prey on native forest birds and seabirds at NPSA, WAPA and possibly AMME, and on shorebirds at all parks.

All parks with native birds are at risk from the potential establishment of the brown tree snake. The nightingale reed warbler at AMME is probably at highest risk. Impacts of predators on native bats are unknown in Hawaii. Any threats known to fruit bats in American Samoa? The brown tree snake depredates native reptiles in Guam and Saipan.

2. Competition from invasive species

Competitive effects on native terrestrial animals are generally poorly documented. Competition has been implied or suggested at HALE by (Loope and Medeiros' paper on game birds cited in Kalij proposal) and Scott et al. for some alien Hawaiian forest birds such as the Japanese White-eye (CITE and check this). The Polynesian-introduced mourning gecko is being displaced by a recently introduced lizard on Oahu (E. Campbell, pers. comm.), although the mechanism for this displacement is not known.

3. Facilitating spread of diseases or pathogens

Mosquitoes and alien birds are responsible for the establishment and spread of avian diseases including malaria and pox in Hawaii. Feral pigs create additional mosquito breeding sites by felling tree ferns and eating the trunk's interior; thus, disease is more prevalent in forest areas with alien pigs (CITE). Avian disease may have caused or contributed to the extinction of several endemic Hawaiian birds, and currently it threatens or limits many surviving species in HAVO, HALE, and possibly KALA. The role of avian disease in American Samoa is a topic of current research (get additional info from LaPointe and Atkinson). Alien birds and possibly other animals imported from the US mainland are potential sources of West Nile Virus, a disease that could prove deadly to some Hawaiian birds including Nene (HALE and HAVO) and `Alala or Hawaiian Crow (not currently found in any Hawaiian parks, but formerly in HAVO). We have found no information on the impact of disease on surviving Guam and Saipan vertebrates.

4. Impacts of aliens on important habitat components

HAVO, HALE, KALA, NPSA and WAPA all have habitat that has been degraded by feral ungulates (unsure about ALKA). Impacts of rats on native plant communities, although documented at HAVO via recent broadcast toxicant work (anywhere else is this documented?), may be underestimated or under-appreciated, and probably affects all parks except USAR. However, we have found little information on the effect of these impacts on native vertebrates. Invasive alien plants in appear to have displaced native Nene food plants.

D. Pollution

AMME wetland, habitat for endangered Nightingale Reed Warbler, is threatened by water quality degradation , flood control and run off from town sewage into wetlands, and encroaching development to wetlands are concerns of habitat degredation. KAHO, PUHO and PUHE wetland habitats, used by endemic water birds and migratory species, are threatened by pollution from upslope or adjacent harbors. Any impacts at NPSA?

E. Water withdrawl

PUHE wetland may be threatened by upslope dewatering. The drop in the watertable due to upslope water withdrawl may reduce freshwater inputs at KAHO, impacting endemic water birds and some shorebirds. Are there wetland areas that are drying up at KAHO possibly due to drop in watertable? Any impacts at WAPA?

F. Coastal changes

Increased human use could cause disturbance to shorebirds, basking and nesting turtles, and basking monk seals within parks. Perhaps more significantly, shorelines outside parks are often heavily used or impacted by nearby development that brings large numbers of people, as well as pets and lights into proximity of coastal wildlife. Thus, the more protected confines of the national parks may become increasingly important refugia for these animals.

G. Other disturbances or catastrophes (tsunami, fire, extensive vegetative changes, urban encroachment)

These large-scale, sudden changes have caused loss of habitat for Bulwer's petrels at HAVO (subsidence associated with a tsunami), and loss of forest for native birds from fire

(HAVO, HALE, WAPA?). Adjacent deforestation outside HAVO (other parks?) has further reduced forest bird habitat. Loss or fragmentation of less disturbed buffer zones outside all parks has accelerated the invasion of alien plants and predators.

H. Habitat restoration.

Wetland habitat restoration to aid recovery of endangered Hawaiian water birds is in the planning stages at KAHO. Other habitat restoration work has been aimed primarily at native plant communities (various forest types, coastal strand, etc. at HAVO), and impacts on native terrestrial vertebrates have not been documented. The exception is native forest bird monitoring in recovering forest at HALE. Fences built to exclude feral ungulates catch nesting seabirds and bats at HALE and HAVO; this is noted opportunistically, although subalpine fence inspections at HAVO will include searches for downed birds. ALKA will encourage communities to engage in habitat restorationand can support existing community efforts aimed at habitat restoration along the trail. Strategically located restoration projects bordering NPS parks units would benefit conservation efforts within parks. Furthermore, NPS units can teach community volunteers in the park how to inventory, monitor and restore native habitats. These skills could then be applied to trail and other areas adjacent to the park.

I. Human harvest.

Composition and processes (important functional roles for these organisms) - both species of fruit bats at NPSA are harvested for subsistence; also Samoan doves (there is a story about the dove according to Peter Craig; contacted my Samoan friend Tavita for clarification but no info yet -cfp). Over fishing and over gathering threatens the sustainability of resources and affect ecosystem balance along the ALKA trail corridor.

See RMPs for additional park-specific issues

Monitoring Programs and methods (previous or existing)

A. ALKA

No known monitoring. However, because the trail passes through national parks, portions of it may have been included in various park inventory or monitoring programs.

B. AMME

A wetlands survey was conducted in FY2001(?). This included a predator study for the endangered warbler, GIS mapping, and inventory of plant species. [We have requested copy of the final report.] A ornithological survey was done in the 1970's by the Army Corp of Engineers of wetlands in Saipan. (Looking for copy of report). Currently there is monitoring of birds by the Division of Fisheries & Wildlife, including the Christmas Bird Counts.

Partners: Northern Mariana College (Saipan Cooperative Research Education & Extension Service), Army Corp of Engineers????

C. HALE

- Park is included in supra-annual forest bird counts conducted by the State and cooperators.

- Additional historical monitoring efforts compiled by SJ Anderson:

- Yoshinaga Veg Plots & Exclosures: Medeiros, Loope, Nani Anderson

- Kaupo, Crater, Hana Rain Forest & Front Country exclosures: Loope, Medeiros

- USFWS Forest Bird Survey: Jacobi: forest & upland birds, ungulate activity, veg plots & incidentals

- Kipahulu Interdisciplinary Study 1983-84; forest bird counts: Banko, Stone; rat trap on 500m transects: etal; inverts: Howarth, Gon, Stone; botanical plots:*** Anderson, L. Pratt, Higashino, Medeiros; weed transects:*** Anderson, L. Pratt, Higashino, Medeiros

- Kipahulu Pig Research 1985-88; ungulate activity: ***Anderson, Stone; veg plots: ***Anderson, stone; weed transects:*** Anderson, Stone

- Ground-nesting endangered birds in crater district (Nënë and 'Ua'u) population monitoring (trends, dynamics, threats, etc.)

- Forest bird populations in recovering rain-forest areas monitoring

- Effects of the removal of feral animals on endangered seabird populations

- Introduced alien mammal monitoring and removal

- Vespula and argentine ant monitoring

- Volcano hazards monitoring ***Anderson indicates possibility of digital data at HALE

Partners: NARS, TNC, MISC, DLNR, Molokai Community Watershed Coalition, Bishop Museum (including All Taxa effort), GAP, Pacific Cooperative Studies Unit (PCSU), current DOFAW / HALE partnership for monitoring seabirds, Nene and forest birds, adjacent ranches and Hawaiian Homelands (Kaupo ranch, Haleakala Ranch, Ulupalaku Ranch, Kahikinui/LIFE), miscellaneous graduate students, National Fish and Wildlife Foundation (currently funding Nene monitoring), National Parks and Conservation Association, American Hiking Society, US Fish and Wildlife Service, Student Conservation Association, Youth Conservation Corp, Maui Forest Bird Recovery Project, USGS-BRD, Natural Resource Soil Council, high schools and local undergraduates, miscellaneous Native Hawaiian organizations (including hula halau, political groups, etc.), Molokai Community Watershed Coalition.

D. HAVO

- Effects of goat and pig removal on vegetation

- Selected bird population monitoring (bird transects)*

- Monitoring of nene, petrel

- Monitoring selected invertebrate taxa in mesic and wet forest, esp. Drosophila

- IBP transects: comment from Rick Camp: Forest bird surveys in HAVO ceased in the mid 1990s. This monitoring program provided critical information on bird distribution and densities along moisture and elevational gradients. HAVO is uniquely situated along a moisture gradient (<1000 - > 4000 cm annual rainfall) ranging from wet to mesic to dry forests. Monitoring bird populations along this gradient provides insight into ecological dynamics and population responses not available elsewhere. The park provided the only recent source of forest bird data along an elevational gradient (2000 – 7000 ft.; East Rift Zone to Mauna Loa Strip transects). Additionally, a long term monitoring program is essential to determining population fluctuations and changes, and species' range contractions/expansion
- Monitoring of small mammal populations in Ola'a, Kipuka Ki, Kipuka Puaulu for both handbroadcast and aerial broadcast of rodenticides FY 00-FY02.

Partners: BRD, HVO, Bishop Museum for invertebrates and their All Taxa project; Olaa-Kilauea Partnership; Hawaii Invasive Species Committee, GAP, Nënë Recovery Action Group, US FWS, PCSU.

E. KAHO

- Waterbird nesting study

- alien vegetation removal

- water quality of Aimakapa pond

- contaminants of Kaloko and Aimakapa ponds

- semi-annual statewide waterbird counts

- marine turtle health and habitat study.

Partners: UHH, Hawaii Invasive Species Committee, Bishop Museum All-Taxa effort, Hawaii Preparatory Academy, Ducks Unlimited.

F. KALA

- Restoration of lowland, coastal Pritchardia forest

- Restoration of lowland dry/mesic forest

- Restoration of coastal strand vegetation

- Ungulate removal from a section of Puu Alii plateau

- Resident Monk Seal beach and shoreline use,

- Goats, pigs, deer (need more info on these—Bryan?)

- Crater plants (need more info on these—Bryan?)

Partners: federal Enterprise Community (EC) designation and implementation, and USDA NRCS Watershed Restoration Action Strategy for the south shore of Molokai, Molokai Community Watershed Coalition, Bishop Museum All Taxa effort, Molokai Invasive Species Committee, GAP, PCSU.

G. NPSA

- Seabird study on Mt. Lata;

- DMWR bird and fruit bat surveys ongoing territory-wide with some stations located within the park, conducted by the local government Dept. of Marine and Wildlife Resources (are there other fruit bat surveys that have occurred in past?—ask Bryan.)

- Seabird study on Mt. Lata: 3 years, in final year

- Whistler's vegetation plots, permanent plots established for park floristic survey, 1994; Travis Heggie: revisited some of Whistler's plots, data are forthcoming

- Feral pig control efforts: ongoing snaring and activity transect data collection, in-house

- Disturbed lands delineation (agroforestry within the park), funded, planned for FY02.

Partners: Local Dept. Marine and Wildlife Resources: bird/bat monitoring; American Samoa Selected Invasive Species Taskforce (ASSIST): cooperative invasive species work; Coral Reef Advisory Group (CRAG): cooperation on many marine issues; Univ. Hawaii: 3-year PhD study of corals in Ofu lagoon; DOC (territory-wide GIS database of benthic marine habitats); USDA: Forest Health Inventory Plots may be established in the park; NOAA (coral reef initiative); PCSU.

H. PUHE

- Shark monitoring in the bay

Partners: Hawaiian Charter School, Mauna Kea Soils and Conservation District, Royal Court Assembly (important caretakers, source of volunteers)

I. PUHO

- Green Sea Turtle inventory and monitoring (George Balazs) was carried out in 2001 and possibly in the past as well. Marine turtles at the Park are quite healthy and free of tumors.

- Inventory of terrestrial arthropods in 2002 along two transects in the Coconut forests of the Wainoni and Keamoali'i areas of the Park prior to removal of 30 years worth of coconut debris. A post debris removal inventory will also be carried out to monitor change in species frequency or abundance if any. David Foote is identifying the arthropods and has, I believe, carried out similar arthropod surveys in the Park in the past.

- Vegetation inventories of the Park were done in 1986 (Smith et al, Tech Report 56) and in 1998 (Pratt, Tech Report 121) with recommendations as to exotic species removal and native plant restoration. Vegetation monitoring began in 1986 (Leishmann, Tech Report 57) with the publication of the first vegetation map based on a 1976 aerial infrared photograph. Deardorff (2002) digitized this map in ArcView and is currently digitizing vegetation of the Park from photographs taken in 1996 (satellite and aerial imagery) with ground-truthing in 2002. The percent change in vegetation will then be calculated using Ecologist's Tool Box. Deardorff intends to publish a Revised Vegetation Management Plan in 2002. GIS vegetation maps are soon to be published on the web by the NPS GIS Clearinghouse.

- Water Quality inventory and monitoring began in 1999 with a study of the water quality of the anchialine fish ponds (Chai and Dendel, UH Internship Program project paper). Deardorff initiated an inventory of water quality of springs, waterholes, anchialine ponds, and nearshore marine waters in 2002.

Partners include USGS, DLNR, UH, PCSU.

J. WAPA

- The Guam Division of Forestry's terrestrial monitoring plots in forest and savanna; WAPA is about to start to a watershed-level project looking at the effects of wildfire on tropical savanna community structure and erosion rates, and the subsequent downstream effects of this erosion (sedimentation) on WAPA's nearshore reefs.

Partners: Guam Division of Forestry, PCSU, Guam EPA, and the Bureau of Coastal Zone Management.

Summary

Table 1. Preliminary table of terrestrial vertebrate monitoring needs in Pacific Island Network parks as identified by the parks.

	Monitoring Needs for Terrestrial Vertebrates
ALKA	Unknown.
AMME	monitoring of endangered birds , inland mangrove wetland hydrology, mangrove forest & wetland assessment and restoration.
HALE	monitoring of T & E Species, seabirds, forest birds and bats
HAVO	rare animal species, including endangered species and species examples of evolutionary processes; forest birds, procellarids, and Nene.
KAHO	monitoring of endemic water birds
KALA	Monitoring of abundance and distribution of all bird species throughout the park, forest bird trends, procellarids.
NPSA	Monitoring of fruit bats, sheath tailed bats, rainforest birds, Tahitian petrels, and seabirds.
PUHE	None
PUHO	Monitoring of T& E species, sensitive , native, and exotic animals.
USAR	Unknown
WAPA	species monitoring in limestone forests and tropical savanna. Public education of I & M, translation into other languages.

Table 2. Network parks identified rare, threatened, endangered and culturally significant species as high priority resources. Parks also identified four main categories of faunal stressors that are of concern.

	Critical Resources			Stressors			
	T & E Species	Rare Species	Species w/ Cultural Significance	Invasive Alien Species	Biodiversity Loss	Climate Change (sea level rise)	Fire or Altered fire regimes
ALKA	P	P	P	P	P	P	P
AMME	S	S	S	S	S	S	
HALE	S	S	S	S	S	S	S
HAVO	S	S	S	S	S	S	S
KAHO	S	S	S	S	S	S	S
KALA	S	S	S	S	S	S	P
NPSA	S	S	S	S	S	S	
PUHE	S	S	S	S	S	S	S
PUHO	S	S	S	S	S	S	S
USAR		S					
WAPA	S	S	S	S	S	S	S

P= Potential S= Self Identified

Further information needs:

- All parks need to have vertebrate NPSpp entries proofed and cleaned. Additional entry needed as follows: (see latest NPSpp taxa-by-park table).

- Basic inventories of terrestrial vertebrate fauna are needed for: ALKA, AMME, and WAPA.

Appendix A: Data (Mining) Sources

SOURCE	Result
Summary from Federal Wildlife Laws Book	Migratory Bird Treaty Act
Summary from Federal Wildlife Laws Book	Hawaii State Wildlife Policy
National Park of American Samoa	Mammal, Bird, reptile, & Amphibian Checklists
DOFAW	list of publications, Conservation plan for Hawaiian Stilts at Cyanotech Aquaculture Facility, Forest Stewardship Handbook, From Urban Landscapes to Native Forests: Invasive species in Hawaii
Chuck Sayon, AMME email	Species list for AMME, no response
American Memorial Park, Saipan	Bird List from Wetland Mangrove Forested Sanctuary
Earl Campbell-USFWS email	FWS putting out a nationwide species list soon.
NATUREBIB	printed out existing references pertaining to terrestrial fauna by park
NPSPP	printed out existing vouchers, observations, species list by park
NPS RESEARCH PERMIT APPLICATIONS ONLINE	Hardcopies of research permits pertaining to terrestrial fauna by park
Hertiage Database	CD of Database received from Sandy Margriter (GIS Specialist)
Aric Arakaki, email	4/9/03 not issuing permits
Ron Nagata, email	4/9/03 using the online permit system, Liz Gordon, Archeologist sort of incharge, haven't seen obs cards being used in awhile
Ana Dittmar, email	4/25/03 not issuing permits, will later check with Malia Laber when she starts work.
Sally Beavers email	4/10/03, will send xerox copies of old permits, not online yet. No obs cards being used

Daniel Kawaiaea/Ben Saldua email	no response
NPSLIBRARY	search library database by park. Saved references on S:/im/ForbesPerryC/ HAVONPSLIBRARY
HARDCOPY FILES FROM MASHURI WAITE	
UHLIBRARY	search library database by park. Saved references on S:/im/ForbesPerryC/HAVOUHLIBRARY
email to Thane Pratt -BRD_PIERC/ PIERC Publications 2001-2003	4/14/03 referred request to David Helwig
Cathleen Bailey, Landscape Workgroup Lead	Sent over a few references that could pertain to landscape
USFWS Publications Online	Recovery Plans for Hawaiian Hoary Bat, & Mariana Fruit Bat (Guam population)
Tavita Togia, Invasive SPP Specialist, NPSA	sent book of Birds of Western Polynesia
Rick Warshauer, BRD_PIERC_HAVO Kilauea field Station	4/21/03 received photos of turtle tracks at KALA
USGS-PIERC-BRD	Publications Database 1993-2000
Ducks Unlimited	Article:Help for Hawaii's endangered Water birds, Hawaii State Bird to Benefit
National Wildlife Research Center (NWRC)	List of publications (keyword Hawaii) 1939-2002
Wendy Schmacher email	4/17/03 this cannot be done yet, but hopefully soon- NatureBib to NPSPP ref automatically
CPSU	List of tech reports 1974-1997
Vitousek Lab Hawaii	List of publications, 1987-2002
DLNR/DOFAW	Programmatic Workplan:2000-2001, Hawn End Bird Conservation Program
Territory of American Samoa	Mission Statement
Territory of Guam	NA
HAVO Library	Need to schedule a time to enter resources into NatBib
KSBE	article: Army and KSBE Work together in the Koolaus
The Peregrine Fund	Article: The Peregrine Funds Hawaii Project
CHEVRON/TEXACO	nothing found
BISHOP MUSEUM/ Hawaii Biological Survey	4 publications from 1992-2003 publications list online
BISHOP MUSEUM	vertebrate database available to search, also library and archives online to search
US ARMY	no publications found on Hawaii programs, error in page

US ARMY Garrison	EMP Bulletins about Hawaii Army Projects
Conservation Council for Hawaii	website under construction, unable to open
Hawaii Audobon Society	Elepaio newsletter (all issues available at HAVO Library)
Honolulu Zoo	didn't find anything about native/alien spp
Malama Hawaii	NA
Na Ala Hele	NA
Hawaii Conservation Alliance	List/ Brief Descriptions of Research Projects Currently in Progress July 1999
Natural Resources Conservation Service	NA
CNMI Government	Div of Fish & Wildlife: End SPP list, Breeding Birds and other bird short articles.
DOI Library	files saved on S://im/ForbesPerryC/HAVODOILIBRARY.txt etc for all parks that had citations
LINDA W. PRATT OFFICE	VARIETY OF PAPERS, RODENTS, AXIS DEER
Guam Community College	Species list of Guam(unofficial)
Guam government website	nothing found
USDA-APHIS- Wildlife Services	Species that Wildlife Services are working on in Guam
USFWS	brief info on Guam Rail
CNMI- Division of Fisheries & Wildlife	Div of Fish & Wildlife: End SPP list, Breeding Birds and other bird short articles, enforcement laws, herps
USFWS	Draft copy of U.S. Pacific Islands Regional Shorebird Conservation Plan

Appendix B: Literature Reviewed

Still in the processes of gathering data on this section

Appendix C: Workgroup Membership

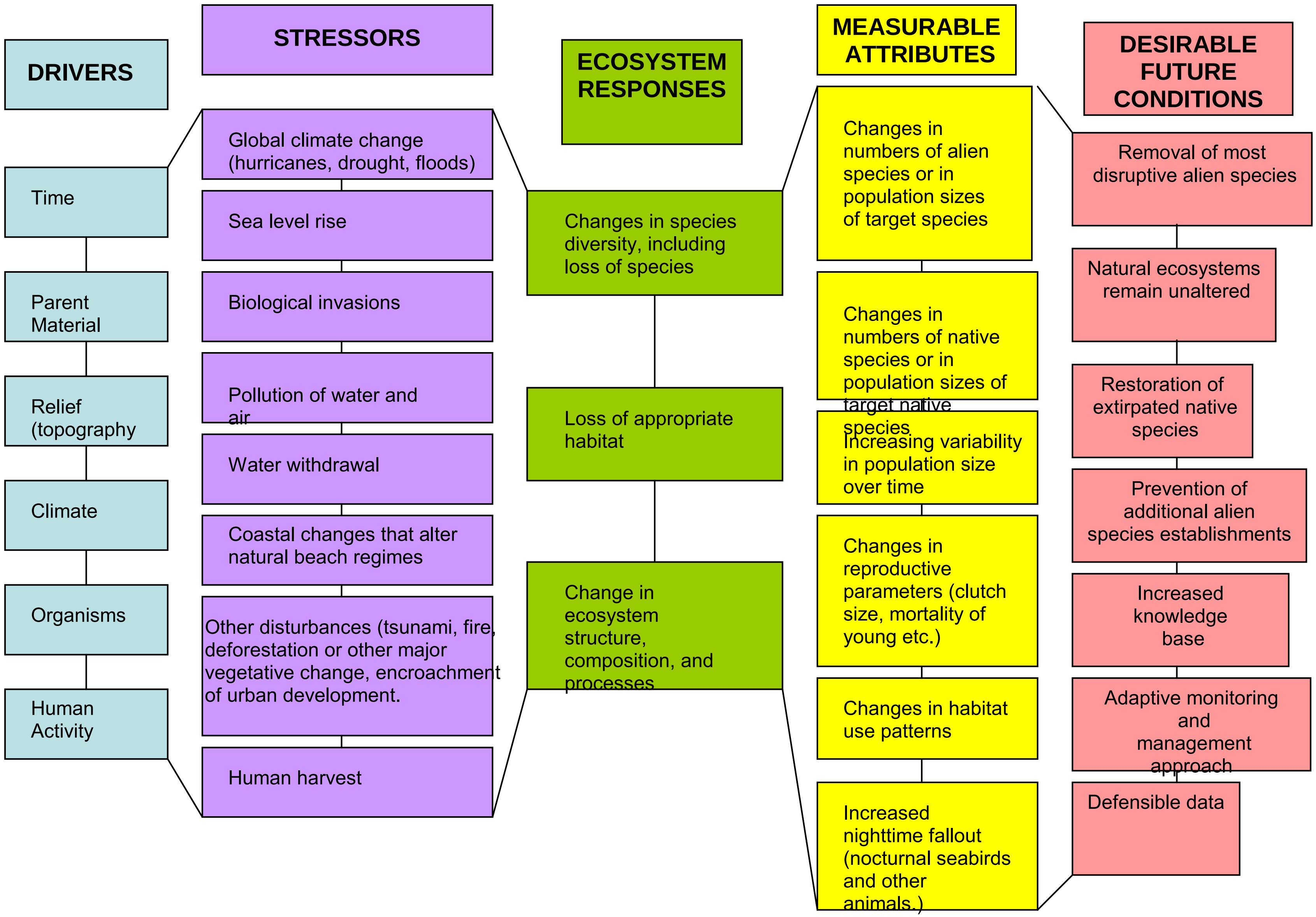

Figure 1. Conceptual ecosystem model for terrestrial vertebrate fauna in the Pacific Island Network.

Vegetation and Flora Workgroup Report

Linda Pratt, Workgroup lead
Ilana Stout, Facilitator

These materials are currently in DRAFT form (as of 3/5/04). The authors have been asked to share these reports for comment in March 2004. In several cases, authors have only had several weeks to work on these materials, and this may be evident in the content of the report. Accordingly, we hope that comments can focus on helping us ensure we have identified the breadth and significance of natural resource and ecological issues in the Pacific Island Network.

Table of Contents

Executive Summary

Ten of the 11 National Parks in the Pacific Island network have vegetation that requires monitoring. The larger parks support a wide diversity of native, near-native, or invaded plant communities, ranging from shoreline to alpine zone and from very wet to very dry climate regimes. Vegetation types include strand, grasslands, shrublands, woodlands, forests, and bogs. The smaller Historical Parks contain remnants of native communities within a broader historical or cultural landscape, but are often highly invaded by alien plant species. Plant species introduced by indigenous people during settlement of the islands are currently a component of many of the parks. Alien vegetation has encroached on native communities and cultural landscapes of all parks.

A monitoring system provides resource managers with information essential to managing vegetation. . Effective monitoring is an early warning system for detecting and eradicating incipient invasive species and produces data on population and community status and trends for developing management strategies. Monitoring addresses changes in the populations of native, alien, culturally significant, and rare plant species. Monitoring also detects changes in plant communities over time and across landscapes. Community monitoring in the parks is typically concerned with successional patterns after fire, alien ungulate disturbance, invasion of alien species, or recovery after management. Monitoring provides information on effects of disturbances, such as fire, hurricanes, subsistence agriculture, and introduced ungulates;

feedback about alien species, restoration programs, and visitor impacts; an assessment of the effects of habitat fragmentation; and a means of measuring progress and meet reporting requirements.

This document is intended to be an overview of the current knowledge regarding terrestrial vegetation resources and current vegetation monitoring in all Pacific Island National Parks. This document also highlights the gaps in our current knowledge, which in some parks are considerable. A summary of each park follows, including geographic setting, legal mandates, existing vegetation resources, critical vegetation resources, stressors, monitoring needs, and current monitoring efforts.

ALKA. The vegetation resources of the recently-designated, 280-km-long (175-mile) Alakahakai Trail have not been inventoried.

AMME. American Memorial Park is a coastal park of 53 ha (133 a) on the island of Saipan in the Northern Marianas. The park was established as a memorial honoring the sacrifices made in the Mariana Islands during WWII. AMME contains a memorial structure surrounded by a mowed recreational area. Most of the park is covered by alien vegetation except for a wetland containing native mangroves (Bruguiera gymnorrhiza) and other indigenous plants. The wetland is the most significant vegetation resource of the park and is habitat for two endangered bird species. The most important stressors are human uses including trampling, illegal harvesting of vegetation, and rubbish dumping. Encroachment from adjacent development may be altering hydrology of the wetland. The most important monitoring need is to follow changes in the wetland community. Baseline transects were established in the wetland in the late 1980s, and additional vegetation studies have recently been completed.

HALE. Haleakala National Park includes approximately 12,000 ha (30,000 a) on the island of Maui, in the Hawaiian Islands. It extends from the shoreline to over 3,000 m (10,000 ft) elevation at the summit of Haleakala Volcano. The park was established to protect and provide access to geological resources, but it also contains significant biological resources. HALE has coastal strand vegetation, highly disturbed lowland wet and mesic forest, intact lowland and montane rain forests and cloud forests, montane bogs, subalpine grasslands and shrublands, montane dry forest remnants, and alpine cinder fields. Recovering alpine-aeolian cinderland, subalpine grassland/shrubland, montane bogs, cloud forest, rain forest, and dry to mesic leeward shrublands and forests are all notable for high native species diversity. The protected rain forests of Kipahulu Valley, a research area and scientific reserve, are particularly important. Subalpine lakes and riparian habitat of perennial streams are valuable resources.

The park supports at least 15 threatened and endangered plant species, a few candidate endangered species, approximately 14 species of concern, and 30 rare plant species. Additional species within these categories have been extirpated from HALE. The main stressors here are those found throughout the Hawaiian Islands: alien plants and animals, including feral pigs, goats, axis deer, rats, ants, yellow jacket wasps, mosquitoes; diseases; potential new introductions; visitor impacts in the alpine zone and riparian areas; loss of key species; and wildfire. HALE managers have identified monitoring needs as rare plant population monitoring; alien plant distribution monitoring, including incipient invaders; continued treatment effectiveness monitoring in areas receiving alien plant control, feral ungulate removal, and restoration of native vegetation; and recovery of significant plant communities. A substantial body of vegetation monitoring has been conducted in HALE, with the intent of establishing baselines for long-term monitoring. Vegetation maps were prepared for three portions of the park with different methods and scales in the 1980s. Much of the rare plant flora has been monitored or inventoried. Monitoring of the threatened Haleakala silversword has been a long-term, systematic program. However, monitoring has been carried out for only short periods in dry forests remnants, montane bogs, and montane rain forest.

Alien plant monitoring methods emphasize checklists, vegetation mapping, alien plant distribution and frequency monitoring along transects, alien plant treatment monitoring or research into control techniques, alien plant species within monitored vegetation communities, and impacts of individual alien plant species. HALE resource managers have been highly successful in removing feral goats and pigs from the park. Monitoring of vegetation recovery was established in subalpine grasslands, leeward shrublands, montane bogs, montane rain forests, and in Haleakala Crater. Some of these projects focused on exclosures predating ungulate removal; others were along long transects. Many of the studies of alien plants and vegetation recovery after ungulate removal could serve as long-term monitoring. Other studies in rain forests, grasslands, bogs, leeward shrublands, and Haleakala Crater may serve as baseline data sets for future monitoring.

HAVO. Hawaii Volcanoes National Park is an approximately 133,000 ha (333,000-acre) area on the island of Hawaii, which was established in 1916 to protect volcanic scenery. In 2003, 46,000 ha (116,000 a) of the adjacent Kahuku Ranch were acquired as an addition to HAVO (then 86,800 ha). The park extends from shoreline to 4,170 m (13,679 ft) elevation. HAVO has coastal strand vegetation, remnant lowland wet and dry forests, dry open woodlands, early successional vegetation on lava flows, montane rain forests, montane mesic forests, montane dry forests, subalpine forests and shrublands, and a sparsely vegetated alpine zone. The most significant vegetation resources are diverse mesic and rain forests of both Mauna Loa and Kilauea; upper montane, subalpine and alpine communities of Mauna Loa; relictual dry forests; lowland ecosystems proposed for restoration; beach strand communities and associated anchialine ponds; and early successional lava flows and kipuka. The vegetation resources of the Kahuku addition have not been evaluated.

Excluding Kahuku, there are 22 threatened and endangered plant species, 5 candidates for endangered status, 22 species of concern, and 40 rare plant species known from the park; these numbers include several extirpated and extinct species. Many native plant species and communities are of cultural significance in the context of traditional gathering. The main stressors are feral ungulates; invasive alien plants; rats; yellow-jacket wasps; mosquitoes; ants; diseases; loss of pollinators; small population size of native organisms leading to loss of endemic plant and animal species; change in nutrient, soil water, and fire regimes; wildfire; lava flows; incompatible uses in adjacent lands; park development; and visitor impacts. The most important monitoring needs are for rare plant populations; alien plant distributions, including incipient invaders; treatment effectiveness in areas receiving alien plant control, feral ungulate removal, and restoration of native vegetation; recovery of significant plant communities; impacts of cultural collecting on the population or community level; effects of fire; long-term changes in rain forests, diverse mesic forests, and upper montane to alpine ecosystems; and early succession on lava flows.

A substantial body of vegetation monitoring has been conducted, although not in a systematic park-wide program. HAVO vegetation was mapped in the 1970s, 1980s, and 1990s, using different classification schemes. Systematic rare plant surveys have been conducted in key communities of the park, including lowland dry forest, montane mesic forest, montane and subalpine dry forest and woodland, and montane rain forest. Selected species in these vegetation types have been monitored for short periods of time. Inventory work was detailed enough to serve as a baseline for future monitoring efforts. Monitoring is associated with out-plantings of nearly 60 rare plant species. The distributions of over 80 species have been mapped for future monitoring. Alien plant frequency transects have been established in the Mauna Loa Strip, managed units of Olaa Forest, East Rift forests, Kipuka Puaulu and Kipuka Ki, Thurston Special Ecological Area, and Kipuka Kahalii. Faya tree (Morella faya) spread and dieback has been monitored throughout its range in the park. Plant succession is being monitored in faya-invaded communities. Monitoring has been established to detect recovery of vegetation after goat removal in the coastal lowlands and Mauna Loa Strip, and after pig removal in East Rift forests, Olaa Tract, and Mauna Loa Strip. Repeated alien plant inventories help to monitor alien plants over time in a qualitative fashion. Fire is a major disturbance factor in HAVO. Plant succession following fire has been monitored in the coastal lowlands, dry ohia (Metrosideros polymorpha) woodlands, montane seasonal forest and shrublands, and rain forest, as well as in nine burns prescribed for restoration purposes. Experimental restoration projects are underway in the coastal lowlands, dry ohia woodlands, koa forest, and abandoned pastures. Vegetation in these study sites is monitored. Many past and current alien plant, fire effects, and recovery-after-ungulate-removal studies can be treated as long-term monitoring.

KAHO. Kaloko-Honokohau National Historical Park is a coastal park of approximately 470 ha (1,160a) that was established to preserve Native Hawaiian culture, with the era of Hawaiian inhabitation as the target for the historical landscape. While remnants of the coastal strand persist and significant wetland communities remain, the vegetation of most of the park has been largely altered by invasive plant species. Two important invasive plants are kiawe (Prosopis pallida) in shoreline and wetland areas and fountain grass (Pennisetum setaceum) on previously bare lava flows. The most critical vegetation resources are the wetlands surrounding two large fishponds, coastal strand, and wetland vegetation around anchialine pools. The park supports a large population of the species of concern Capparis sandwichiana and smaller numbers of two other rare plant species. The main stressors on vegetation are development of coastal lands near the park, alien plant species, erosion of sandy shoreline, invasive alien ungulates, rats, ants, loss of biodiversity, and visitor impacts to natural resources. Potential stressors include rising sea level due to global warming, expansion of the adjacent Honokohau Harbor, additional development of upslope lands, increased visitation, and invasion of new alien plants and animals. The most important monitoring needs are for wetland communities, native tree and shrub populations, effectiveness of native plant re-introductions in alien plant removal areas, and alien plant treatment effectiveness. KAHO vegetation was mapped in the 1980s. Baseline studies on three rare plant species could be re-monitored. Monitoring of alien plant species consists of treatment effectiveness records. Baseline inventory data on alien and native plant distributions could be developed into a long-term monitoring effort.

KALA. Kalaupapa National Historical Park encompasses approximately 4,365 ha (10,778 a) on the island of Molokai, where the park was established to preserve the cultural landscape of a

Hansen's disease colony, along with scenic values of the area. KALA has coastal strand, loulu palm (Pritchardia hillebrandii) coastal forest, remnant lowland mesic forest, native vegetation on cliff faces, and lowland rain forest. Montane rain forests and wet cliff vegetation covers most of the Puu Alii Naural Area Reserve, within the authorized boundaries of KALA. Critical vegetation resources are the upper-elevation rain forest of Waikolu Valley and Puu Alii, diverse dry forest in Kauhako Crater, and coastal strand communities. The park supports or formerly suppported 27 plant species listed as endangered, 2 threatened plant species, 5 candidates for endangered status, and at least 22 species of conern. `Awiwi (Centaurium sebaeoides), an endangered annual herb, and the threatened Tetramolopium rockii var. rockii are strand community components. Several endangered plant species have been reported from Kaluapapa Peninsula, and others may be found on unsurveyed cliffs in or near the park. Offshore islets support unusual relictual vegetation, as well as the endangered plant species Scaevola coriacea and Brighamia rockii. A large number of endangered species and species of concern are known from rain forests of Puu Alii NAR; a few of these have not been observed for many years and are likely extinct.

The main stressors at KALA are human impacts on offshore islands; invasive alien plants and animals (ungulates, rats, mosquitoes, ants); diseases; and loss of biodiversity. Potential stressors are altered disturbance and succession regimes and new invasive alien plants and animals. The chief monitoring needs are rain forest, dry forest, and strand community recovery after feral ungulate removal; Pritchardia coastal forest restoration; rare plant population monitoring; vegetation mapping at a scale showing native vegetation fragments and patch size; and rain forest boundary mapping. Vegetation has been mapped in the coastal strand and in portions of the park uplands. Monitoring programs have been designed for four endangered plant species and for rare plants of Kauhako Crater. KALA does not have specific monitoring of alien plants but restoration projects focused on Kauhako Crater and the coastal strand have included alien plant monitoring components. These projects may also contribute to assessment of vegetation recovery after ungulate removal. Kauhako Crater monitoring, coastal plant inventories, offshore islet surveys, and vegetation data from upper-elevation Forest Bird Survey transects, could be developed further for a long-term monitoring program.

NPSA. The National Park of American Samoa includes more than 3, 640 ha (9,000 a) in four units on four islands of American Samoa. The legislation establishing the park recognized the importance of the Samoan tropical forests as one of the last remaining undisturbed paleotropical rain forests and as habitat of Pacific flying foxes. The four units of NPSA have vegetation ranging from coastal strand and littoral forest to Dysoxlum lowland rain forest, montane rain forest, and summit scrub dominated by ferns. Apart from littoral plants at the shore, rain and cloud forests were thought to be the original vegetation cover of all the islands of Samoa. The current vegetation of American Samoa is the result of thousands of years of human disturbance from agriculture and logging. Montane rain forest and summit scrub is most vulnerable on Tutuila, and the lowland (Dysoxylum samoense) rain forest is a critical resource of Tau. All other native vegetation types in the park are important, as they are unique among NPS units. Rare plant species need to be identified and protected; no plants are currently listed as endangered, but several are considered species of concern. Native fruit-bearing tree species are important as food sources for rare fruit bats (Pteropus samoensis, P. tonganus) and uncommon Many-colored Fruit Doves (Ptilinopus perousii). Plants of ethnobotanical importance are also potential monitoring subjects.

The important stressors on vegetation are expansion of subsistence agriculture into forests, invasive alien plants and animals (feral pigs, rats, ants, etc); and diseases. Potential stressors are new invasive alien species, climate change, hurricanes, incompatible tourism-related development on adjacent lands, and human population growth leading to loss of habitat for native species. The most important monitoring needs at NPSA are rain forest ecosystem health; expansion of subsistence farming and effects of human disturbance; ungulate impacts on native vegetation; alien plant distribution monitoring; effectiveness of weed treatment and ungulate removal; and population trends of rare plants (once they are defined). Mapping efforts at NPSA include a 1981 coastal management atlas, a vegetation survey and forest inventory, generalized vegetation types in the 1994 General Management Plan, vegetation type maps for Tau and Tutuila, and a land delineation effort in 2002 that recognized management and land use categories. Park-wide rare plant and alien plant monitoring programs have not been initiated, but baseline information for future monitoring efforts has been provided by recent plant inventories in three units. Long-term vegetation plots have been recently established in several vegetation types of the Tutuila unit.

PUHE. Puukohola Heiau National Historical Site is a 35-ha (86-a) coastal park on the island of Hawaii that was established to protect Hawaiian culture and historical sites. The era of Hawaiian inhabitation, specifically the period of heiau or temple construction (ca. 1790), is the target historical period. Natural vegetation has been largely replaced by alien vegetation, and many native species exist in the park only as plantings by park staff. PUHE has the most altered vegetation of the four Hawaii Island parks. Critical vegetation resources are concentrated in the strand and small wetland community. Experimental areas in which pili grass (Heteropogon contortus) is being restored are important as examples for future restoration efforts. A population of the rare pololei fern (Ophioglossum polyphyllum) persists at one site in the park. The primary threats to the park's resources are invasive alien plant species, particularly kiawe (Prosopis pallida), puncture vine (Tribulus terrestris), fountain grass (Pennisetum setaceum); alien trees, shrubs, and vines that may damage cultural resources; pickleweed (Batis maritima) recently removed from the coastal wetland; fire; erosion; and in-park development. Potential stressors are development of a liquid-fuel storage facility adjacent to the park; resource damage from fuel spills and increased visitation from adjacent Kawaihae Harbor; and damage from off-road bikes or motorcycles using the coral flats and stream banks. The perceived information needs are treatment effectiveness monitoring in areas converted from alien vegetation to pili grassland; population monitoring of the rare pololei fern; and monitoring of re-introduced native plants and restored communities. A vegetation map has not been prepared for PUHE. Little alien plant monitoring has been done but a 30-year old study of roadside alien plants could be replicated in a portion of the park.

PUHO. Puuhonua o Honaunau National Historical Park is comprised of 74 ha (182 a) on the coast of Hawaii Island; it was established to protect Hawaiian culture and historical sites. The era of Hawaiian habitation is the target historical period. Most natural vegetation has been replaced by alien species, but many Polynesian and indigenous species have been planted by park staff near the Visitor Center. The critical vegetation resources are coastal strand and marsh surrounding anchialine pools; these support primarily native vegetation. Other native plants are found scattered in vegetation dominated by alien plants. One species of concern and several uncommon lowland plant species are known from the park. Endangered loulu palms (Pritchardia affinis) have been planted near the Visitor Center. The detached upland garden has out-plantings of several additional endangered plant species. The stressors are erosion of coastal areas, particularly with rising sea level due to global warming; incompatible development encroaching on the park; invasive alien plants, including those already established (Leucaena leucocephala and Pithecellobium dulce) and invaders not yet in the park (ivy gourd or Coccinia grandis). Perceived monitoring needs are: population monitoring of selected native and Polynesian plant species; community-level monitoring of coastal strand and wetland vegetation; effects of alien plant treatments: and success rates of native plant re-introductions. A vegetation map was prepared in the 1980s. PUHO has a long history of alien plant control, and park monitoring consists of tracking treatment effectiveness. A pilot monitoring project to determine frequency and abundance of native plants and invasive alien plant species in the mid 1990s could be repeated. No other vegetation monitoring programs are ongoing.

USAR. The USS Arizona Memorial is a 4-ha (10-a) site in Pearl Harbor, island of Oahu, Hawaii. There are no terrestrial vegetation resources in this park unit.

WAPA. War in the Pacific National Historical Park is dispersed over seven units with a total area of approximately 400 ha (1,000 a) in the Territory of Guam, Mariana Islands. The enabling legislation states that the campaigns of the Pacific theater of WWII are to be commemorated and the natural and scenic values of Guam are to be conserved. WAPA supports coastal vegetation, limestone forest, savanna, and ravine or riverine forest, as well as disturbed areas of secondary vegetation. Critical vegetation resources are limestone forest remnants, savanna vegetation recovering from fire, and riverine forests. The Asan Inland and Asan Beach units comprise an entire sub-watershed. Stressors to WAPA vegetation are wildfire and subsequent erosion, particularly in savanna vegetation; adjacent incompatible development; invasive ungulates (feral pigs, Philippine deer); alien plants; the Brown Tree Snake (Boiga irregularis) that has decimated bird populations, thus reducing pollinators and seed dispersers; and severe typhoons that repeatedly disturb vegetation cover, particularly in limestone forest. Monitoring needs are studies of fire effects and erosion in savanna vegetation; impacts of feral ungulates and alien plant species; and changes in limestone forest composition and cover. The vegetation of WAPA has not been specifically mapped, but a broad-scale vegetation map of Guam applies to the park units. The flora of WAPA has not been inventoried. Park units may contain several species of concern and plants recognized as rare by the Government of Guam, but probably do not support Guam's one Federally-listed endangered plant species. No vegetation monitoring has been carried out in WAPA.

Introduction

A. General Definition of Topic Area:

Vegetation and flora monitoring includes the study of alien and native plant species populations and plant communities. Population monitoring addresses changes in populations of incipient invasive species and alien plants established in the parks, Polynesian introductions, harvested species, other key native species, and rare species including those llisted as Threatened or Endangered. Community monitoring includes quantitative monitoring and vegetation mapping of the spatial distribution of plant communities. Community monitoring typically addresses successional patterns following fire, ungulate disturbance, or invasion of alien plants;

recovery after alien species control; and ecological restoration efforts. Community monitoring and vegetation mapping may be used to analyze vegetation change from the perspective of the vegetation landscape (including landscape metrics such as fragmentation and patch size).

B. Monitoring Goals.

A monitoring program will provide data for the following goals:

- An early warning system for managers about newly invasive plant species, changes in established alien plant populations and plant communities, and loss of rare or key native species to help develop effective control and mitigation measures.

- Information about status and trends in plant populations and communities to better understand them and develop strategies for alien species control and ecological restoration programs.

- Feedback about effects of disturbance, alien species control, ecological restoration, and rare species management programs to help managers manage adaptively.

- Assessment of the effects of habitat fragmentation, development of strategies for conservation partnerships, and evaluatation of landscape level restoration attempts.

- Progress measurement and reporting requirements of the performance management system, Endangered Species Act, and other Congressional mandates.

C. Role of monitoring program

The monitoring program will operate within an adaptive management feedback loop to help establish and evaluate alien species control, ecological restoration, and rare species recovery programs. Some monitoring activities will provide long-term monitoring apart from specific management treatments, but most monitoring will be tied to management treatments.

Mandates to Consider

A. Park enabling legislation.

HALE and HAVO legislation do not have specific language regarding vegetation. For PUHE, the enabling legislation names Kamehameha the Great and John Young and specifies the period of Kamehameha's ascendancy to power (ca. 1790) as the historical time that the Park commemorates. PUHO and KAHO were established to protect Hawaiian cultural and historical sites, and the era of Hawaiian inhabitation is the model for the historical landscape. The natural resources of KALA are not addressed in the establishment act, except as "scenic resources." ALKA legislation does not mention vegetation or natural resources of the 280-km (175-mile) historic trail. The enabling legislation of WAPA states that the campaigns of the Pacific theater of World War II are to be commemorated, and the natural and scenic values of Guam are to be conserved. Likewise, AMME was established on Saipan to honor those who died in the WWII Mariana Islands campaign, and no vegetation management is specified. The act establishing NPSA recognized the importance of the park's tropical vegetation as one of the last remaining undisturbed paleotropical forests and as habitat of Pacific flying foxes.

B. Endangered Species Act.

All the National Parks of the Hawaiian Islands, except USAR and ALKA, support endangered plants or species of concern. PUHE and PUHO currently contain only planted individuals of endangered species, but several endangered plants may have been among the original coastal vegetation of the parks. The three other Western Pacific parks do not contain federally listed endangered plants. Although WAPA has not been surveyed, it probably does not support the one federally listed endangered plant species of Guam; that rare tree, Serianthes nelsoni, is thought to persist only on Anderson Air Base (USFWS 1994). Endangered plant species have not been designated for American Samoa, although several Samoan plants are listed as species of concern. Parks with endangered species resources are expected to conserve their habitat under the Endangered Species Act of 1973. Recovery plans for individual species or groups of species address the actions needed to recover endangered species. Critical habitat designations for endangered plants of the Hawaiian Islands include areas within several National Parks.

C. NPS Management Policies.

Through monitoring programs, parks will develop data to manage vegetation resources. Whenever possible, natural processes will be relied upon to maintain native plants and communities. Monitoring data are needed to determine the efficacy of this approach. More intrusive management is frequently needed in island ecosystems, because of invasive species problems. NPS management policies include provisions for preserving and restoring native plant populations and communities of parks and restoring those extirpated by human actions. Seeds, cuttings, or transplants may be used for reintroductions. If control is feasible, alien or exotic plant species are to be managed where they interfere with natural processes, impact the perpetuation of native species, disrupt the genetic integrity of native species, damage cultural resources or landscapes, or pose a hazard to public health and safety. Parks will maintain and restore the diversity of genotypes or genetic diversity appropriate to the park unit and needed for long-term fitness of species. The parks will actively manage threatened and endangered plant species, as well as “species of concern,” through inventory, survey, monitoring, and restoring habitat. Managers will attempt to recover endangered species native to the park units by manipulating target rare plant populations by out-plantings and seeding or other recovery techniques. Guidelines for revegetation in disturbed areas of National Parks were given in the 1993 Western Regional Directive WR-94 (NPS 1993). The primary goal of park revegetation is “...the preservation of native plant species, community types, and ecosystem processes.” Culturally significant vegetation may also be preserved by revegetation.

D. Local Controls and Regulations.

The State of Hawaii has legislation that allows for the listing of endangered plant species at the State level. To date, no plants other than those recognized on Federal endangered species lists have been listed as threatened or endangered. The State of Hawaii has noxious weed regulations that recognize some alien plant species as particularly invasive and permits State agencies to cooperate with landowners and provide herbicides, equipment, and personnel to control infestations (State of Hawaii 1992). However, compliance with the regulations is not evenly enforced, and many of the worst alien plant species are not listed as noxious weeds because they are considered too widespread to control. HAVO has developed protocols for rare plant seed collection and propagation, greenhouse sanitation procedures, and out-planting strategies to prevent the unintentional spread of alien weed seeds and invertebrate pests (Tunison 2000). Other non-NPS groups have developed standard protocols for propagating and out-planting rare plant species in natural areas (Hawaii Restoration Group; Hawaii Pacific Endangered Plant Recovery Coordinating Committee).

Geographic Setting and Conceptual Models

A. Geography:

All the network parks are found on tropical islands in the Pacific Ocean. Eight of the parks are in the Hawaiian Islands in the Central Pacific between 19 and 22 degrees North latitude. HAVO, KAHO, PUHE, PUHO, and the recently designated ALKA are on the island of Hawaii, the youngest of the main Hawaiian Islands at the southern and eastern end of the archipelago. HAVO is located on the southeast slope of Hawaii Island, where it extends from sea level to the summits of Kilauea and Mauna Loa Volcanoes. The newly designated Kahuku unit of HAVO is positioned on southern Mauna Loa and extends down both eastern and western flanks of the volcano. PUHE, KAHO, and PUHO are coastal parks of the western or Kona side of the island; KAHO is centrally located with PUHE to the north and PUHO to the south. HALE is on Maui, the second youngest Hawaiian Island; HALE extends from sea level to the summit of East Maui. KALA is on a peninsula projecting from the north shore of Molokai, centrally located in the main Hawaiian Islands. USAR is within Pearl Harbor on southern or leeward Oahu. Two of the network parks are situated in the western Pacific Ocean between 13 and 15 degrees north latitude in Micronesia. WAPA is on the western side of the island of Guam and AMME is on the west coast of Saipan, one of the Northern Mariana Islands. NPSA is on Polynesian islands of American Samoa, approximately 13 degrees south latitude. One unit of NPSA is on the island of Tutuila; three others are on Tau, Ofu, and Olosega of the Manua Island group 96 km (60 miles) east of Tutuila.

B. Geology:

The Hawaiian Islands and American Samoa are oceanic volcanic islands arising from hotspots. Guam and Saipan have more complicated geologic origins involving both vulcanism and subduction of the Marianas Trench. The northern half of Guam and portions of Saipan have limestone substrates elevated above the weathered volcanic base. The park units of WAPA are on the volcanic substrates of the southern half of Guam, but at least one unit includes elevated limestone caps. The parks of the island of Hawaii are on active or dormant volcanoes. A significant proportion of HAVO is covered with recent lava flows that are sparsely vegetated. HAVO contains the rift zones and summit calderas of both Mauna Loa and Kilauea Volcanoes, two of the most active volcanoes on earth. All substrates of KAHO are flows from Hualalai Volcano less than 10,000 years old, including one sparsely-vegetated lava flow dated at 1,000-3,000 years (Moore et al. 1987). PUHO is on prehistoric pahoehoe flows of Mauna Loa, and PUHE substrates are old weathered soils of Kohala Volcano. Haleakala of Maui is inactive and the volcanoes of Moloka`i and O`ahu are extinct. HALE protects the summit of Haleakala with its impressive Crater, which is the result of stream erosion, the merging of Kaupo and Keanae Valleys, and subsequent volcanic activity. KALA encompasses the Kalaupapa peninsula, formed on the north shore of Molokai during the Pleistocene (MacDonald and Abbott 1970).

The parks of the Western Pacific are on islands (Guam and Saipan) with long-extinct volcanoes. The oldest of the Samoan Islands are dated at more than two million years, but there was volcanic activity between Tau and Olosega approximately 150 years ago (Whistler 1994).

C. Elevation Gradients

Among the Hawaiian parks, HAVO and HALE have the greatest elevational range, extending from sea level to the summits of tall volcanoes >3,000 m (>10,000 ft) elevation. KALA has an elevational range from sea level to almost 1,220 m (4,000 ft) elevation. The three parks of leeward Hawaii Island are coastal and extend upslope to an elevation no more than 100 m. ALKA is also in the coastal lowlands of western and southern Hawaii Island. Among the three Western Pacific parks, AMME is restricted to the coastal lowlands on the western shore of Saipan. WAPA includes coastal units and inland sites on the slopes of Mt. Alifan and Mt. Tenjo; one unit extends to above 305 m (1,000 ft) elevation. NPSA is composed of four units; Ofu and Olosega are largely coastal but the Tutuila and Tau Units range from sea level to 491 m (1,610 ft) and 966 m (3,170 ft) elevation, respectively.

D. Rainfall and Climate

The largest two Hawaiian parks, HAVO and HALE, include within their boundaries several climatic zones with a range of rainfall regimes. HAVO contains two of the four rainfall minima of Hawaii Island, the Kau Desert with mean annual rainfall <750 mm and the interior lands of Mauna Loa with <500 mm annually. The highest mean annual rainfall within the park is found in Olaa Tract, a rain forest with >4,000 mm per year (Giambelluca et al. 1986). In general, the eastern windward portion of HAVO has high rainfall, which diminishes upslope, particularly above the trade wind inversion layer near 1,830 m (6,000 ft) elevation. The upper elevations of the park are moist to very dry, and the summit of Mauna Loa receives on average <500 mm precipitation. The leeward, western portions of HAVO are in rainshadows of Mauna Loa and Kilauea summit, and are typically dry. HALE also has a range of climates, as it extends from sea level on the windward, eastern slope of Haleakala to the summit of East Maui. The park also includes lands in the leeward rainshadow of Haleakala, down to 1,220 m (4,000 ft) elevation. Annual precipitation in the park varies from 1,250 mm in the Crater, southern slope, and Kaupo Gap to >6,000 mm on the upper northeastern slopes of Haleakala. KALA, on the north shore of Molokai receives 1,000 mm of precipitation annually at sea level and >3,000 mm at the upper elevations of Waikolu Valley (Giambelluca et al. 1986).

The three Historical Parks and ALKA trail on the Kona coast of Hawaii Island are in relatively low rainfall areas with constant warm temperatures and pronounced daily wind patterns of land and sea breezes (Blumenstock and Price 1967). KAHO has a mean annual rainfall of approximately 600 mm and a seasonal climate with higher rainfall during summer months (Canfield 1990a). The climate of PUHO is similar to that of KAHO; PUHO has mean annual precipitation of 659 mm, and highest monthly mean rainfall occurs in January and the summer months between June and September. PUHE is located within one of the four rainfall minima of the island of Hawaii and receives <250 mm of rain annually (Giambelluca et al. 1986). The USAR on Oahu has no actual land area, but is located within Pearl Harbor on the dry leeward side of the island in an area than has on average 600 mm rainfall per year.

The climate of Guam and the Northern Marianas (CNMI), including Saipan, is warm, wet, and tropical. Temperature varies between 90 and 70o F. Relative humidity is high, often exceeding 80% and seldom falling below 50%. The rainfall pattern is strongly seasonal with a wet season from July to November and a pronounced dry season from December to June. Average annual rainfall of the Marianas is 2,160 mm (85 in) (Baker 1951), and on Guam the annual mean is 2,175 mm (Mueller-Dombois and Fosberg 1998). Typhoons are yearly events, which occur during the monsoonal wet season. Trade winds blow from the northeast, but easterly and southeasterly winds prevail during several months in the spring (Baker 1951). Because Guam and the Marianas are relatively low islands, there is no pronounced rainshadow effect, and leeward shores are not drier than those of the windward sides (Mueller-Dombois and Fosberg 1998).

NPSA has a warm tropical climate with little seasonal variation in temperature. Rainfall is high in the four units of the park. On Tutuila, annual rainfall averages 3,200 mm (at the airport), and may be even higher on the upper mountain slopes within the park. Rainfall is seasonal with greater monthly means from October to May and a dry season from June to September. Hurricanes are occasional but not annual events (Whistler 1994). Tau Island unit is only about 96 km (60 miles) east of Tutuila and shares its warm and wet tropical climate. Tau average rainfall is more than 2,500 mm per year and is highest in December. The dry season is June to September, and droughts sometimes occur on the island (Whistler 1992).

E. Natural and Existing Vegetation

Among the Hawaii parks, the two largest have the greatest diversity of existing vegetation and the highest proportion of natural vegetation (although disturbed to some degree). HAVO has coastal strand vegetation, remnant lowland wet and dry forest, dry open woodlands, early successional vegetation on lava flows, montane rain forest, montane mesic forest, montane dry forest, subalpine forest and shrubland, and a sparsely vegetated alpine zone (Doty and Mueller-Dombois 1966). HALE has coastal vegetation, highly disturbed lowland rain forest and mesic forest, intact lowland and montane rain forest, montane cloud forest, montane bogs, subalpine grasslands and shrublands, alpine aeolian cinder fields, montane dry forest remnants, and leeward mesic shrublands. KALA has coastal strand, loulu lelo (Pritchardia hillebrandii) coastal forest, remnant lowland mesic forest, native vegetation on cliff faces, lowland rain forest, and, in Puu Alii, montane rain forest and wet cliff shrublands. Natural vegetation of the three Kona Historical Parks (PUHE, KAHO, and PUHO) has been largely replaced except for coastal strand and wetland vegetation. AMME is covered by alien secondary vegetation and planted ornamentals, except for a wetland and coastal mangroves. Seven WAPA units support coastal vegetation, limestone forest, savanna, and ravine or riverine forest, as well as disturbed areas of secondary vegetation (Fosberg 1960). One of the units contains a forestry planting of West Indian mahogany (Swietenia mahogani). The four units of NPSA have vegetation ranging from coastal strand and littoral forest to Dysoxlum samoense lowland rain forest, montane rain forest, and summit scrub dominated by ferns (Whistler 1992, 1994). Mueller-Dombois and Fosberg (1998) suggested that, apart from littoral vegetation, rain and cloud forests were the original vegetation cover of all the islands of Samoa. They interpreted the current vegetation of American Samoa as the result of thousands of years of human disturbance from agriculture and logging.

F. Conceptual Model:

The Conceptual Model for the Vegetation and Flora of the Pacific Islands National Parks follows the general format of Chapter 2. Stressors or natural drivers are listed with the vegetation attributes affected by them. Within the attributes are listed the impacts to the resources caused by the stressors. Indicators are listed for most impacts and specific measures to use in monitoring are suggested.

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Network-wide Issues

A. Detection and Control of Incipient Invasive Plant Species Threats

All parks face alien species threats. Many threatening species have become established recently in the parks or on the home islands of the parks. Other threats are likely to be introduced to the islands. Some of these species may dramatically alter natural vegetation or vegetation elements of cultural landscapes. Assessing the threat posed by incipient invasive species and detecting their presence are important monitoring functions for Pacific Island Parks to insure proactive and cost-effective management

B. Loss of Native Ecosystems or Vegetation Elements of Cultural Landscapes through Alien Species Invasions

In the Pacific Island Parks, alien species invasions have altered many ecosystems and vegetation components of cultural landscapes by displacement of native species and increased habitat fragmentation. Monitoring changes in native ecosystems and vegetation components of cultural landscapes allows park managers to understand habitat loss, control alien species, and restore natural vegetation.

C. Loss and Restoration of Key Native and Polynesian Species, Including Harvested Species, Threatened, Endangered, and Other Rare Species

With the loss of native plant communities or vegetation components of cultural landscapes due to invasive species or habitat change, populations of important native and Polynesian species are depleted or locally extirpated. Understanding changes in populations of these key species is important for their restoration or maintenance.

D. Effectiveness of Alien Species Control and Ecological Restoration Programs

Most of the parks have established programs to control alien species and restore native ecosystems or the vegetation components of cultural landscapes. Monitoring is required to understand how the programs have achieved their objectives.

E. Effects of Habitat Fragmentation on Viability of Key Native Species and Plant Communities

The Pacific Island Parks are small landscape elements of their islands. They are often surrounded by developed or managed landscapes or natural landscapes highly altered by invasive species. The long-term viability of key native species and plant communities is problematic in this context. Monitoring is needed to assess changes created by habitat fragmentation and to evaluate efforts to sustain viable systems and populations through partnership programs.

F. Effects of Disturbance, such as Fire, Hurricanes, Subsistence Agriculture, and Feral Pigs

These disturbance sources are capable of creating rapid large-scale changes in species composition and community structure. Monitoring is important for understanding these changes and making appropriate management responses.

G. Effects of Management Programs on Vegetation and Populations

Park management programs for visitor services, infrastructure development, resource protection, and resource harvesting, may affect park plant life. Restoration or alien species control programs may cause both positive and negative changes in park vegetation. Monitoring is needed to understand the impacts of management programs.

Monitoring Programs and Methods

A. Vegetation Mapping

1. Existing Maps

Vegetation of all the Hawaiian parks has been mapped except for PUHE, ALKA, and USAR. These maps vary in scale and methodology. HAVO vegetation has been mapped in entirety twice: in 1974 by Mueller-Dombois and Fosberg and by Jacobi et al. as part of the USFWS Hawaii Forest Bird Survey in 1979-82. Mueller-Dombois produced a vegetation map of the coastal lowlands in 1980. Sections of HAVO have been mapped more recently; Loh mapped 90% of HAVO in the 1990s based on 1992 false IR aerial photography (Loh, in prep.a). HALE vegetation mapping has not been carried out park-wide in one project. Vegetation of the Crater District was mapped at a scale of 1:24,000 by Whitaker (1980). The lower section of Kipahulu Valley below 700 m elevation was mapped by Smith et al. in 1985. Jacobi et al. mapped most of HALE as part of the USFWS Hawaii Forest Bird Survey (Jacobi 1989). A composite of these three maps was generated, but normalizing the disparate classification schemes allowed for only a very broad classification. Since the early 1990s, vegetation data have been collected using a modification of Jacobi's community descriptions. These description data have been recorded at rare plant observation and outplanting sites throughout the park, including mid-elevation Kipahulu Valley weed transects. The purpose of these descriptions is to obtain ground-truthing data for the creation of a detailed vegetation map. KALA vegetation has not been mapped in entirety, but the upper forested part of the park, including Puu Alii and some of Waikolu Valley, was sampled by two transects of the USFWS Hawaii Forest Bird Survey (Jacobi 1989). Canfield (1990b) mapped the coastal strand communties of Kalaupapa. Two of the three Kona Historical Parks have relatively recent vegetation maps. KAHO vegetation was mapped by Canfield (1990a) in 1987, using aerial photographs from 1959 and 1982. Leishmann (1986) mapped PUHO vegetation, using 1976 infrared aerial photographs. Vegetation of both parks was examined on the ground before mapping. Based on later ground surveys in 1993-94, the vegetation of both these parks has changed considerably, and previously recognized mapping units now differ in vegetation structure or dominant plant species (Pratt and Abbott 1996 a; 1996b). The vegetation map of PUHO has been recently updated (D. Deardorff, pers. comm. 2003).

In the western Pacific AMME of Saipan has been mapped twice. Falanruw et al. (1989) mapped the vegetation of AMME as part of a project covering the islands of Saipan, Rota, and Tinian. Raulerson and Rinehart (1989) mapped the vegetation of AMME using a 1987 aerial photograph and data from four transects in the park's wetland. WAPA vegetation has not been specifically mapped, although general vegetation types within the park units may be recognized on vegetation maps of Guam (Mueller-Dombois and Fosberg 1998). The U. S. Forest Service has recently completed an island-wide survey and map (D. Minton, pers. comm.). Mapping efforts at NPSA include a 1981 coastal management atlas, a vegetation survey and forest inventory (Cole et al. 1984), generalized vegetation types in the 1994 GMP, vegetation type maps for Tau (Whistler 1992) and Tutuila (Whistler 1994), and a land delineation effort in 2002 that recognized management and land use categories.

2. New Maps, using accepted methodology

No park of the Pacific Network has mapped vegetation according to current I & M program standards. Jacobi thoroughly mapped HAVO in the late 1970s based on 1977 black-and-white aerial photos, and these maps are available in digital format. Loh mapped 90% of HAVO in the 1990s based on 1992 false IR aerial photography. These new maps are potentially linkable to the NVCS and are in a digital format.

3. Fuels Maps

Fuels are characterized and monitored by preparing fuels distribution maps. These indicate the spatial arrangement of fuel types, based on vegetation structural characteristics and known or suspected fire behavior. HAVO has prepared quadrangle-based fuels maps for all but portions of two quads in the southwestern part of the park. Fuels maps were prepared from vegetation maps by combining detailed vegetation units into a smaller number of fuel types. As vegetation and fuels change, vegetation unit or fuel types can be re-monitored or remapped using vegetation mapping techniques followed by classifying new vegetation units into fuels types. The other parks in the network do not have detailed fuels maps. Basic fuels maps can be developed on a small scale. Detailed fuels maps require detailed knowledge of fuels and fire behavior.

B. Rare Plant Monitoring.

1. HAVO

HAVO (exclusive of Kahuku) has 22 threatened or endangered species known from the park (and several additional endangered species out-planted but not native), as well as 5 candidate endangered species, 22 species of concern, and approximately 40 rare or depleted native species. While many of these have been inventoried as part of Special Ecological Area surveys, few have active or recent monitoring programs. Rare plants of the rain forest were inventoried in the 1990s (Pratt and Abbott 1997, Pratt et al. 1999, Belfield 1998) and baselines exist for future monitoring. Several rare plant species of wet and mesic forest, which are hosts for native pomace flies (Drosophila spp.), were monitored for 2-4 years as part of a research project (Pratt and Foote, unpublished data). Rare plants of montane mesic forests were inventoried (Pratt et al. in prep.), and a subset of 15 species have been recently monitored (Belfield pers. comm.) Two threatened or endangered plant species of montane and sub-alpine dry forests were monitored for more than five years (Belfield and Pratt 2002); populations of other rare upland plants have been found and mapped but are not currently being monitored. A significant population of the endangered Portulaca sclerocarpa at a geothermal area was monitored at an interval of ten years (Pratt and Abbott, unpublished data), and a second desert population was studied for a shorter period (Belfield and Pratt, unpublished data). P. sclerocarpa declined at both sites; trampling by humans was identified as a possible limiting factor. Rare plants of three remnant lowland dry/mesic forests were inventoried in the 1990s (Abbott and Pratt 1996), and a subset has been monitored as part of a rare plant stabilization project. One endangered species of the lowlands (Sesbania tomentosa) was mapped in the 1990s, and a subset was visited to determine growth and persistence. Density and mortality of another lowland species of concern (the sedge Fimbristylis hawaiiensis) were followed in 20 small plots for five years (Belfield and Pratt, unpublished data). The rare plants of the Kahuku addition have not been inventoried, but preliminary monitoring of the endangered Mauna Loa or Kau silversword (Argryoxiphium kauense) is underway. Surveys of the most diverse vegetation and older substrates of Kahuku are planned for FY 2004.

At HAVO, volcanic activity is a real or potential negative impact on rare plant populations. This is particularly important for rare and endangered plant species of the forests of Kilauea's East Rift, but virtually every part of the park is vulnerable to lava flows. In prehistoric times, such natural disturbance would likely not have caused the extirpation of a species from a region. Today most rare plants have very limited distributions, and protected natural areas are few and scattered. Therefore lava flows and concomitant wildfires may lead to the loss of rare and endangered species from HAVO, and fires may lead to losses from two of the Kona parks. Monitoring of volcanic activity and dating of lava flows are important aspects of an overall rare plant and vegetation-monitoring scheme.

Rare plant limiting factors research has not been carried out at HAVO, but loss of natural pollinators is thought to be a factor in the rarity of some endangered plant species. A recent monograph of the endemic Hylaeus yellow-faced bees (Daly and Magnacca 2003) provided records of visitation by yellow-faced bees to the flowers of several endangered plant species, such as Sesbania tomentosa. Basic studies on insect pollinators and seed predators of rare plant species would be worthwhile, and monitoring of alien insects may be an important part of a strategic recovery plan for many endangered plants of HAVO and the other Hawaiian parks. Research on the impacts of alien yellowjacket wasps (Vespula pensylvanica) may identify native insect pollinators that serve as prey of the wasps. Toxicant research may lead to management techniques to reduce the threat of the wasps in native ecosystems (Foote, unpublished data). Another group of alien invertebrates that may impact endangered plant species includes slugs and snails. Alien slugs have been implicated as depredators of native plant seedlings, flowers, and fruits. Basic monitoring of slug populations and slug damage to plants may be part of an overall program to monitor rare plants. The contribution of plant diseases to native plant rarity is largely unknown. Basic research has been done to identify diseases of important native plants, such as koa (Acacia koa) (Hodges and Gardner 1984), mamane (Sophora chrysophylla) (Gardner 1997a), aalii (Dodonaea viscosa) (Gardner 1988), and others (Gardner 1997b), but no systematic ecological monitoring of the extent of disease infestation has been carried out in HAVO or the other Pacific Network Parks.

2. HALE

HALE has 15 threatened and endangered plant species extant and five others that have been extirpated. An additional 11 species are candidates for endangered status and at least 22 are species of concern. Approximately 30 additional species are rare, and many of these may be lost in the next decade. It is estimated that 17 plant species have been extirpated from the park; nine of these are now extinct and eight others persist on island (Medeiros et al. 1998; S. Anderson and P. Welton, pers. comm. 2003). Monitoring of the threatened Haleakala silversword, one of the best known and charismatic of Hawaii's rare plant species, has been carried out for several decades (Loope and Crivellone 1986). Rare plants of montane bogs were monitored throughout the 1980s (Loope et al. 1991; Medeiros et al. 1991), and vegetation of the same montane bogs was re-monitored ten years later (Hotchkiss and Werner in prep.). Rare plant species of remnant dry forests were inventoried (Medeiros et al. 1986), and data could be used for a monitoring program. Haleakala sandalwood (Santalum haleakalae), an uncommon species of the subalpine shrubland, has been monitored in an exclosure for more than a decade. Rare plants of the montane rain forest of Kipahulu have been sampled on transects and in plots that could be used for monitoring (Anderson et al. 1983-86). The Hawaii Forest Bird Survey plot data may be a valuable baseline for rare plants of the montane rain forest. Rare plant observations are currently maintained in a database with information such as number of individuals, size and age class, phenology, alien threats, site description, and GPS location. Rare plant monitoring is one of the priority vegetation monitoring projects (Patti Welton, pers. comm.). As at HAVO, research and monitoring of limiting factors are needed to understand the status of many of the rare plants of HALE. Visitor use is probably not an important factor in the decline of the park's endangered plants, but past disturbance and collecting of silverswords by visitors was a significant impact on that spectacular species.

3. KALA

KALA Peninsula lowlands and offshore islets support (or formerly supported) at least five endangered plant species, one threatened species and at least eight others that are species of concern. If the plants of Puu Alii are included in park totals, KALA has recent or historical records of at least 29 threatened and endangered plant species, 5 candidates for endangered status, and more than 22 species of concern. Additional native species are rare within the park. A monitoring program has been designed for the threatened Tetramolopium rockii var. rockii and the endangered Centaurium sebaeoides (Medeiros and Chimera 1997). Rare plants of Kauhako Crater, including ohe makai (Reynoldsia sandwicensis), a species of concern, were tagged, measured, and evaluated in 1995 to provide a baseline for future monitoring (Medeiros et al. 1996). Plants of Okala Islet were recently inventoried (Wood and LeGrande 2002); one endangered species (Scaevola coriacea) and four species of concern were found. Among the rare species of the islet is Pittosporum halophilum, a tree formerly thought to be extinct. This tree was also recently discovered within the park on the small peninsula of Kukaiwaa. The endangered lobelioid Brighamia rockii has been studied and monitored on offshore islands of KALA since 1994 (Gemmill et al. 1998; Wood 2002).

4. KAHO

KAHO has one candidate endangered plant species (Bidens micrantha subsp. ctenophylla) and two species of concern. The Bidens population has declined to few individuals, and the species requires re-introduction rather than monitoring. Recent outplantings of Bidens will be monitored for survival. One of the species of concern (Fimbristylis hawaiiensis) was monitored in fountain grass removal plots for two years (Pratt unpublished data). There are data on transect frequency and density for pua pilo (Capparis sandwichiana) that could be repeated to monitor the status of this SOC within the park (Pratt and Abbott 1996a). Recently, Randy Nagle inventoried six rare plant species in an 35-ha (86-acre) parcel in the southern part of the park; these rare plants included the candidate endangered Bidens micrantha, the species of concern Capparis sandwichiana, and depleted common species Plumbago zeylanica, Psydrax odorata, and Dodonaea viscosa. Individual naio trees (Myoporum sandwicense) were previously mapped within the park. Additional rare and endangered plant species appropriate to the coastal lowlands of Kona will be introduced to KAHO in the future, and the success of these restoration projects will be monitored (Stan Bond, pers. comm. 2003).

5. PUHO

PUHO supports only one known individual of the species of concern Capparis sandwichiana. A few other native species are rare and depleted at PUHO, but are not considered rare island-wide (Pratt and Abbott 1996b). The endangered coastal loulu palm (Pritchardia affinis) has been planted near headquarters. Several endangered species are cultivated in the disjunct upland garden parcel, including Pritchardia shautaueri. There is currently no rare plant monitoring ongoing.

6. PUHE

PUHE has no naturally occurring threatened or endangered plant species, but ohai (Sesbania tomentosa) historically occurred within the park (D. Kawaiea, pers. comm. 2003). Three endangered plants and one species of concern have been planted in the park: ohai; mao hau hele, Hibiscus brackenridgei; loulu, Pritchardia affinis; and mao or Hawaiian cotton, Gossypium tomentosum (Pratt and Abbott 1996c). A population of the rare pololei fern (Ophioglossum polyphyllum) has been monitored by park staff for more than a decade.

7. AMME

AMME has no listed threatened or endangered plant species, but at least one orchid species (Zeuxine fritzii) has been identified as rare (Raulerson and Rinehart 1989).

8. WAPA

WAPA lacks a vascular plant inventory, and its rare plant resources are largely unknown. It is unlikely that the park supports the only Federally listed endangered plant species recognized on Guam (Serianthes nelsoni), as this species is thought to be extant only in the northern section of the island (USFWS 1994). Nonetheless, it would be worthwhile to search for this endangered tree species in at least one of the park units, as its type locality is “Upe District and hills back to Abu” (Stone 1970), a site near Mt. Tenjo. It is possible that one of the other two species recognized as endangered by the Government of Guam may be present in WAPA. The tree fern Cyathea lunulata or “tsatsa” may occur in protected ravines within savanna vegetation; the species is considered to be very rare on Guam (Raulerson and Rinehart 1992). One or more of the four orchid species endemic to Guam and the Mariana Islands may grow within the park. Previously, the U. S. Fish and Wildlife Service (1995) listed two Guam orchids, two fern species, and one vine in the Moonseed Family (Tinospora [Tinosperma] homosepala) as candidates for endangered species status. Currently, two orchids (Coelogyne guamensis and Nervilia jacksoniae), two ferns (Thelypteris warburgii and Lycopodium phlegmaria var. longifolium), and the Moonseed vine are listed as Species of Concern, and one small tree in the Plumeria Family from Guam and Rota (Tabernaemontana rotensis) is considered a candidate for listing (USFWS 2001). Tabernaemontana is known from only one limestone forest site on Guam (Stone 1970), and is probably not a component of park vegetationu. However, the rare vine Tinospora has been recently reported within the park (D. Minton, pers. comm.). Rarity of the park's native plant species should be evaluated and a list of sensitive native plants developed before comprehensive monitoring is undertaken. Typhoons are a frequent disturbance factor on Guam and may impact populations of rare plants or their habitat in the park units. Investigation of the effects of such storms should be a component of a rare plant monitoring scheme.

Monitoring of the alien brown tree snake (Boiga irregularis) is relevant to rare plants on Guam and indriectly to those of Hawaii. Native songbirds are important agents of pollination and seed dispersal, and the bird populations of Guam have been decimated by the brown tree snake. If bird-eating snakes become established in the Hawaiian Islands, rare plant populations may be negatively affected. Efforts to detect incipient invaders such as snakes are critical to the long-term survival of native birds and rare plants in the Hawaiian Islands (Kraus and Cravalho 2001).

9. NPSA

NPSA has benefited from recent plant inventories of its three units (Whistler 1992, 1994). None of the vascular plants of the park is listed as endangered, but a list of plants rare in NPSA and on the islands of Tutuila and Tau could be generated from Whistler's checklists. Three species collected on Tutuila (Elatostema tutuilense, Litsea samoensis, and Manilkara dissecta) and one species from Tau (Acronychia retusa) are currently considered Species of Concern (USFWS 2001). No rare plant monitoring is underway, but the vegetation plots of Whistler (1994) or Heggie and Cairns (2001) might be used for future monitoring of rare tree species.

C Alien Plant Monitoring

1. HAVO

With more than 600 species of alien plants known from HAVO (Higashino et al. 1988a), alien plant monitoring must be an important component of the park's vegetation inventory and monitoring program. HAVO has many current and past monitoring projects that involve alien plants. They are of three basic types: distribution and frequency transects or mapping projects, alien plant treatment effectiveness monitoring, or monitoring of alien species in vegetation community studies. Recently, a series of research projects have focused on characteristics or negative impacts of single alien plant species.

Alien plant frequency transects have been established in the Mauna Loa Strip, Olaa Forest managed units, East Rift forests (Pratt et al. 1999), Kipuka Puaulu and Kipuka Ki, Thurston SEA, and Kipuka Kahalii (Pratt, unpublished data). A number of alien plant mapping projects were accomplished as a first step in the development of control and containment strategies (Tunison 1992a). Firetree or faya (Myrica faya, now Morella faya), banana poka (Passiflora mollissima, now P. tarminiana), and blackberry/raspberry (Rubus spp.) were the focus of island-wide distribution maps that included HAVO (Whiteaker and Gardner 1985, 1992;

Warshauer et al. 1983; Gerrish et al. 1992). A more recent effort was made to map the current park distribution of faya or firetree (Camrath et al. 1997). The distribution of fountain grass (Pennisetum setaceum) was mapped in and near HAVO, and control strategies were developed to contain and eventually eradicate this highly invasive species from the park (Tunison 1992b). Alien grass communities of the park's coastal lowlands were mapped by Mueller-Dombois in 1982. Localized alien plant species within HAVO were mapped throughout the park (Tunison et al. 1992) and on roads and trails in and near the park (Stemmermann 1987). Common mullein (Verbascum thapsus) was recently surveyed in the Mauna Loa Strip, where it has been established since the 1970s (Loh et al. 2000). Recent monitoring of invasive alien plants has been carried out along primary and secondary roads in HAVO (Bio et al. in prep.) and on park trails (Benetiz in prep.). The role of visitors as distributors of weed seeds along trails during organized races was addressed by Higashino et al. (1983). Monitoring of seeds brought in on the shoes of runners has continued sporadically for 20 years.

Alien plant treatment effectiveness monitoring has been carried out by Resources Management personnel, and detailed results of experimental herbicide trials and larger tests of management techniques are contained in RM files. This RM alien plant monitoring has been concentrated in Special Ecological Areas, which contain the most important natural resources of the park and receive the most intensive management attention (Tunison et al. 1986). Many alien plant monitoring projects have been focused on finding effective treatments for suites of weed species that have invaded Olaa Tract, Kipuka Puaulu, Kipuka Ki, the Crater Rim forests near Thurston Lava Tube, Ainahou Ranch, Naulu Forest, the Keamoku lava flow, and more than ten other areas. Monitoring was established to follow changing frequency or density of alien plants after control efforts, particularly in Olaa Forest, Kipuka Puaulu, and firetree-infested woodlands (Tunison and Stone 1992). Techniques to kill localized alien plants have also been investigated (Tunison and Zimmer 1992). Over the last two decades, several research projects focused on determining efficacy of various herbicides and application rates (Eldredge and Gardner 1984; Santos et al. 1986, 1992). Some of the most highly invasive alien plants in the park, such as banana poka, yellow Himalayan raspberry (Rubus ellipticus), firetree, and strawberry guava (Psidium cattleianum), were studied in multi-year research projects involving herbicide tests (Santos et al. 1991a, 1991b; Gardner and Kageler 1982; Cuddihy et al. 1991; Pratt et al. 1994).

Many studies of plant communities in HAVO have an alien plant-monitoring component. Park Naturalists G. O. Fagerlund and A. L. Mitchell pioneered early vegetation studies inHAVO. The archives and research files have copies of some of these studies, such as a quadrat-charting project established in the coastal lowlands. Checklists of alien (exotic) plant species in the park (Fagerlund 1947; Fosberg 1966) give us information on introduction dates and original range of many weeds. The International Biological Program or IBP (Mueller-Dombois 1970, Mueller-Dombois et al. 1981), the Ohia Dieback Project (Mueller-Dombois 1974, 1977, 1980, 1985), and the Hawaii Forest Bird Survey (Scott et al. 1986; Jacobi 1990) supported studies in HAVO that involved vegetation monitoring with an alien plant component. Succession studies of invasion and recovery of vegetation after the 1959 Kilauea Iki eruption documented the timing and invasive potential of alien plant species on new substrates eruption (Smathers and Mueller-Dombois1974). Follow-up studies in the same area monitored the success and population structure of native and alien shrub species (Wright and Mueller-Dombois 1988) and examined the association of firetree with other alien plants (Mueller-Dombois and Whiteaker 1990).

Much preliminary ecological data, including information about alien plants and vegetation, were collected within HAVO in the early 1960s and summarized by Doty and Mueller-Dombois (1966). In the 1980s, vegetation was sampled at several sites along the East Rift of Kilauea near the park's boundary with Kahaualea to establish a baseline prior to proposed geothermal development (Cuddihy et al. 1986). In the 1990s, vegetation, bird, and insect monitoring projects were focused on newly designated SEAs (Stone 1990); the results of some of these studies remain unpublished. Weed frequencies were mapped along transects in several SEAs; at some sites, frequency data were compared with results from earlier sampling along the same transects. Forests of the East Rift (Pratt et al. 1999), Naulu, Kealakomo (Abbott and Pratt 1996), and Olaa (Pratt and Abbott in prep.) were the focus of several monitoring projects that included alien plant monitoring, as well as assessment of recovery from feral animal damage and monitoring the distribution and abundance of rare native plant species .

A number of studies have been focused on firetree or faya and its impacts on native plant communities and ecosystem processes. Vitousek and Walker (1989) detailed growth and germination patterns of firetree and investigated its input of nitrogen to the ecosystem. Walker and Vitousek (1991) studied the direct impacts of firetree on the dominant native tree ohia (Metrosideros polymorpha). Lipp (1994) investigated ecophysiological constraints to the invasion of firetree into montane rain forests and dry lowland areas. More recently, a collection of technical reports summarized current research and management of firetree in HAVO (Tunison in prep.). Currently, dense faya stands in the park are the subject of research that includes a management technique component and incorporates seed bank studies and monitoring of surrounding vegetation (Loh in prep.b).

Other alien plants have received considerably less research attention. Banana poka was the subject of research that included Olaa Tract as a study site (LaRosa 1984, 1992). The spread of yellow Himalayan raspberry within Olaa Forest was evaluated by Stratton (1996). Recently, common mullein (Verbascum thapsus) distribution and density were mapped on the Mauna Loa Strip, and potential control methods were assessed (Loh et al. 2000). Studies of alien birds as dispersers of weeds may also contribute to the design of a monitoring program (Kjargaard 1994; LaRosa et al. 1985). The role of alien birds as seed predators has not been fully investigated, but one new research project will attempt to document the role of introduced kalij pheasants (Lophura leucomelanos) as seed consumers and dispersers (Pratt and Hu, in prep; Postelli, unpublished data.). A few weed germination studies have been carried out by Resources Management personnel, and one seed bank study at a lowland forest of Kealakomo monitored seed rain and analyzed seed banks of native and weed species (Drake 1998).

2. HALE

The most recent published checklist of flowering plants and gymnosperms in HALE documents 301 alien species (Medeiros et al. 1998); this amounts to 53% of the park's flowering plant (and conifer) flora. This list does not include plants of the recently acquired Kaapahu parcel that is currently being inventoried (Welton and Haus, in prep.). An earlier assessment of the worst alien plant invaders and strategies for their control recognized 334 introduced vascular plant species in HALE (Loope et al. 1992). Few alien fern species are found in the park. Herat et al (1981) listed only two non-native ferns in the Crater District, and a checklist of Kipahulu Valley contained only 9 alien species of a total 98 fern taxa (Higashino et al. 1988b). Similarly to HAVO, HALE alien plant monitoring falls into several categories: vegetation mapping, distribution and frequency monitoring, alien plant treatment monitoring or research into control techniques, alien plant species within the vegetation community, and impacts of individual alien plant species. Old checklists are valuable historical documents and allow determination of the approximate timing of alien plant invasions and intensification. HALE has one checklist of vascular plants of the Crater District (then Haleakala District of Hawaii National Park), dating from 1945 (Mitchell). Another set of checklists resulted from the Resources Base Inventory or RBI (Stemmermann et al 1981 and Herat et al. 1981). Kipahulu Valley was inventoried before it was added to HALE (Lamoureux in Warner 1967), and there were additions and updated checklists of the Valley's flora (Lamoureux and Stemmermann 1976; Higashino et al. 1988). HALE staff maintains a current updated plant species list (Haus et al., unpublished data).

Data on weed distribution and estimated abundance were collected within plots at stations on transects throughout the park, (within both the Crater District and Kipahulu Valley), as part of the Forest Bird Survey (Jacobi 1989). Alien plant frequency transects were established in 1983 as part of an interdisciplinary study and were continued and expanded as part of a feral pig study. Weed data were summarized by Anderson et al. (1992). Information on weed distribution in Kipahulu Valley was provided by Yoshinaga (1980) prior to the interdisclipinary study, so there are repeated weed data sets for the area. A long transect on the edge of the upper plateau in Kipahulu was used to track alien plant distributions along a heavily used trail (Medeiros et al. 1992). Australian tree ferns (Sphaeropteris cooperi) were studied in large quadrats at 730 m (2,400 ft) elevation in the lower Kipahulu Valley (Medeiros et al. 1992, 1993). Between 1990 and 2003, four long transects, stretching from 670 to 1,400 m (2,200-4,600 ft) elevation, and six short 500-m-long transects were established in the lower Kipahulu Valley rain forest to monitor weed distributions and frequencies. Currently, weed distributions and densities throughout the park are recorded, along with alien plant control efforts, in a GIS-linked Access database (Welton, Haus, et al., unpublished). Bog vegetation, including alien plant species, was monitored in several bogs within and near the park (Medeiros et al 1991, Loope et al 1991). In the Crater District, alien plants were monitored as part of a study at Puu Mamane (Loope and Medeiros, unpublished data), and baseline data on alien cheatgrass (Bromus tectorum) were collected in each of Whiteaker's (1980) vegetation units in 1993 (Loope and Medeiros, unpublished data). The distribution of cheatgrass (Bromus tectorum) in the Crater District was mapped in the mid 1990s (Weller 1993). Within Kaupo Gap, transects and plots sampled vegetation, including alien species (Medeiros and Jessel, unpublished data 1987). Six transects were established in Kaupo Gap to monitor cover of molasses grass (Melinis minutiflora) (Medeiros and Loope, unpublished data 1989). Vegetation plots were established in Kaupo Gap in the 1990s to monitor aalii (Dodonaea viscosa) stand structure in West Kaupo, restoration of vegetation in East Kaupo, and the efficacy of the monocot-specific herbicide fusillade on molasses grass and native shrubs. Weeds, particularly alien grasses, were a component of several studies in the high-elevation grasslands of Kalapawili carried out by Jacobi (1981), Medeiros and Nishibayashi (unpublished 1986), Medeiros and Jessel (unpublished, 1987), and Anderson et al. (1992). Coastal strand vegetation was monitored to detect alien plant invasion in one small area of native vegetation (Medeiros and Jessel, unpublished 1990), and the native grass Panicum fauriei var. latius was followed inside an exclosure near Puhilele Point (Welton, unpublished 1993). Exclosures were built to document recovery of native vegetation from damage by feral ungulates in several ecological zones of HALE; there is typically an alien plant-monitoring component to these projects (Loope and Scowcroft 1985).

3. KALA

KALA does not yet have a specific monitoring program to evaluate alien plant species throughout the park, but several established projects at Kauhako Crater (Medeiros et al. 1996) and in the coastal zone of the park (Canfield 1990) addressed alien plant species and could be replicated as part of a monitoring program. Monitoring designed to follow rare plants in two exclosures (Medeiros and Chimera 1997) could be used to determine the impact of alien plants on the endangered Centaurium sebaeoides and the threatened Tetramolopium rockii var. rockii. A monitoring program has been designed to track survivorship, threats, and pollination success of the endangered Brighamia rockii and Scaevola coriacea on offshore islets at KALA, and weeds of offshore islets have been evaluated (Wood 2002, unpublished; Wood pers. comm. 2003). At least two transects established during the Forest Bird Survey 25 years ago were placed within or near the upper reaches of KALA, and these may provide some data on the presence/absence and relative abundance of alien plant species in the park's rain forest. Surveys of inaccessible areas of KALA planned for FY2004 will also provide data on alien plant threats to rare native species.

4. PUHO

Vegetation at the three Kona Historical Parks is dominated by alien plant species. PUHO has a long history of alien plant control since its establishment in 1961. The area near the Visitor Center and the Great Wall of the Puuhonua has been repeatedly cleared of alien vegetation, and several additional significant historical sites within the park are currently the focus of alien plant control efforts. More than half of PUHO remains covered by alien shrubland, which is dominated by ekoa (Leucaena leucoecephala) mixed with other shrubs and grasses, particularly Guinea grass (Panicum maximum). Monitoring of alien plants at PUHO is primarily treatment effectiveness monitoring. In 1992-94, a set of systematic transects were established throughout the park, along which weed frequency and estimated cover-abundance data were collected (Pratt and Abbott 1996a). These baseline data might be used in a monitoring program to determine trends in alien plant cover. The vascular plant checklist generated during the 1992-94 project, along with an earlier list from a survey in 1982-83 (Smith et al. 1986), provides a baseline of the park's current floral composition and may be used to document future incursions of alien plants.

5. KAHO

KAHO, although a newer addition to the Park Service, also has a relatively large portion of the park targeted for alien plant control. There is currently no alien plant monitoring being carried out, other than informal evaluation of treatment effectiveness. Fountain grass (Pennisetum setaceum) has been cleared from several sites near Kaloko Pond. Fountain grass and assorted alien shrubs are rountinely removed from the 1.5 km stretch of the Mamalahoa Trail that crosses the park; several other trails along the coast and around Kaloko Pond are also maintained by clearing alien plants. Alien grasses and shrubs have been recently controlled in seven acres along the new interpretive trail to Honokohau Beach; mechanical clearing allowed existing native plants to remain undisturbed. These recent alien vegetation-clearing projects used park staff, PCSU personnel, Hawaii Emergency Environmental Workforce crew, and YCC student workers. Clearing of invasive plants has fulfilled park goals of fire management, visitor safety, ecosystem restoration, and protection of cultural sites (Stan Bond, pers. comm. 2003). The General Management Plan (1994) proposed eventual clearing of most alien vegetation and its replacement with native or culturally important plant species. Monitoring of alien plant composition and cover should be part of the vegetation management program in the park. Vegetation sampling before and after alien plant clearing would assist with evaluation of treatment effectiveness and allow for development of efficient re-treatment schemes. It would also be worthwhile to document the appearance of newly invasive alien plants and the relative cover of native and alien plants at some sites of high natural value (i.e. wetlands near Aimakapa and vegetation surrounding anchialine pools). In a project similar to that at PUHO, seven systematic transects were established crossing the park from the upper boundary to the coast. In 1992-94, weed frequency and estimated cover-abundance data were collected in a belt along transects (Pratt and Abbott 1996). These baseline data might be used in a monitoring program to determine trends in alien plant cover. A vascular plant checklist was developed during the 1992-94 project and revised several years later (Pratt 1998). Comparisons with an earlier checklist from a survey in 1988 (Canfield 1990) indicated that alien plant species continue to appear in KAHO as invaders from nearby areas, particularly along roads, trails, and in disturbed areas.

6. PUHE

PUHE is the smallest of the Kona Historical Parks and has the most altered vegetation of the three. Only the coastal strand and brackish pool support native vegetation within the park (excepting plantings of native species near Park Headquarters). The park has a recent checklist of vascular plants, but no baseline vegetation monitoring was established during the last plant survey (Pratt and Abbott 1996c). In a previous survey of the vascular plants of PUHE, Macneil and Hemmes (1977) established 19 transects (15-m long) at 100 m intervals along Highway 27 and the old Spencer Beach Road (see also Croft et al. 1976). The purpose of the monitoring was to detect roadside introductions of alien plants; the method used was measurement of percentage cover of plants in 1-m2 quadrats at 2-m intervals along transects. Transects and plots were not located during the most recent plant survey, but the methods of Macneil and Hemmes could be replicated and monitoring data compared with that collected almost 30 years ago. Currently, alien plant removal projects are focused on several priority species that are invading a coastal wetland (Batis maritima) or interfering with the viewscape from the imposing Puukohola Heiau (kiawe, Prosopis pallida). Widespread weeds, such as buffelgrass (Cenchrus ciliaris), or highly invasive species still localized in PUHE (fountaingrass, Pennisetum setaceum; puncture vine, Tribulus terrestris; and koa haole, Leucaena leucocephala) are treated in portions of the park (Amerling 1997). Other alien plant species are kept from growing on archaeological sites or trails. There will likely be an alien plant component in current and future restoration projects, such as the rehabilitation of the area formerly covered by a roadway that passed through the park at the base of Puu Kohola Heiau.

7. AMME

At AMME, Raulerson and Rinehart (1989) installed four transects in wetland vegetation along which they collected frequency and cover data on all plant species. They used these data to calculate importance values for all plant species in four strata along each transect. As many of the plants encountered on two of the four transects were weedy species not native to Saipan, this research may be considered a baseline alien plant monitoring project. Non-native trees planted as ornamentals near park structures have not been recently evaulated.

8. WAPA

No monitoring of alien plants has been undertaken at WAPA, but a current research project focused on savanna vegetation may provide some baseline information on both native and alien plant species (Dwayne Minton, pers. comm. 2003). One recent proposal submitted as part of a rehabilitation plan following Supertyphoon Paka recommended establishment of photo points at Agat Invasion Beach and the Asan Bay overlook. The proposal involved use of archived photographs from 1944 as baselines for comparison with modern photographs. The goals of the project were to monitor the historic scene, recovery of vegetation, and weed invasion (Anderson 1998). The rehabilitation plan was not funded. The frequency and severity of typhoons relate to the invasion and increase in cover of alien plant species. Monitoring the impacts of typhoons on the vegetation structure and plant composition of Guam forests may be an important part of any alien plant monitoring scheme developed for the park units.

9. NPSA

The vegetation of three of the four NPSA units was described by Whistler (1992, 1994). Checklists produced for Tutuila and Tau are very thorough and distinguish plant species documented within the park from those on the islands likely to be present. Ninety-six non-native plant species are found on Tutuila; most of these are members of the Grass (Poaceae), Sedge (Cyperaceae), Daisy (Asteraceae), and Pea (Fabaceae) Families (Whistler 1994). There are approximately 85 alien plant species (modern introductions) on Tau, along with 40 Polynesian introductions and 329 native vascular plant species. The most invasive alien plant species noted by Whistler (1992) on Tau were Koster's curse (Clidemia hirta), a newly established weed, and mile-a-minute vine (Mikania micrantha), present in Samoa more than 100 years. Other alien species reported from Western Samoa, but not yet in American Samoa are of concern; the most invasive of these are African rubber tree (Funtumia elastica), giant sensitive plant (Mimosa invisa), and night-blooming cestrum (Cestrum nocturnum). More recently, Space and Flynn (2000) reported on 30 invasive alien plant species commonly found in NPSA and recognized 25 additional alien species that are potentially agressive. Apart from 11 vegetation plots on Tutuila and one on Tau, the Samoan plant inventories did not result in a system to monitor alien plant cover or abundance. Whistler focused on native tree density and basal area and did not sample ground cover or alien vegetation, but the sample plots are potentially valuable for monitoring native trees. There may be some alien plant species monitoring carried out as part of feral pig activity monitoring on Tutuila. Recently albizia (Falcataria moluccana) has invaded NPSA, and has been mapped and partially controlled on Tutuila. A proposal to control and eliminate the tree from the park has been developed (Monello 2003a). Alien plants and Polynesian introductions may be used to identify secondary vegetation on formerly cultivated lands within park units.

D. Recovery of Vegetation after Feral Animal Removal.

1. HAVO and HALE, general

HAVO and HALE have expended great effort over the last three decades to remove feral animals from areas with high natural value (SEAs in HAVO, Kipahulu Valley and Haleakala Crater in HALE). At HAVO, feral goats (Capra hircus) have been largely eradicated, and feral pigs (Sus scrofa scrofa) have been fenced out and removed from approximately 1/3 of the park`s rain forest. Mouflon sheep (Ovis musimon) are recent invaders, which are difficult to exclude by standard fencing. Domestic and feral cattle (Bos taurus) were removed from HAVO more than

50 years ago (25 years for the Ainahou Ranch in-holding), except for temporary incursions from adjacent ranches and the occasional feral cow in East Rift forests. HALE shared the same suite of feral ungulates, and has had spectacular results with projects to build exclusionary fences and remove feral goats and pigs. Axis deer (Axis axis) are a potentially serious threat to HALE vegetation, although the species does not seem to be established yet within the park.

2. HAVO

Domestic cattle were the focus of early studies of the impacts of ungulates on native vegetation in HAVO (Baldwin and Fagerlund 1947). After the removal of cattle from the Mauna Loa Strip in 1948, cattle were not a significant disturbance factor in HAVO. Recently, plots from the cattle and koa forest study in the 1940s were relocated and monitored (Tunison et al. 1995); this effort allowed the 50-year old plots to contribute to a long-term data set. One research project compared grasslands and shrublands protected from cattle inside the park with those in adjacent ranchland (Cuddihy 1984). In the last three decades, HAVO monitoring of vegetation recovery has been focused on feral pigs in rain forest and goats in subalpine shrubland, montane dry/mesic forests, and lowland grasslands. Feral goats formerly occurred in great numbers in the coastal lowlands; an eradication program began in 1970 (Baker and Reeser 1972) and successfully removed goats from the lower reaches of the ark within a decade. Two exclosures were built (at Kukalauula and Puu Kaone) to monitor recovery after goat removal; monitoring continued for ten years (1971-1980) (Mueller-Dombois and Spatz 1972, 1975; Mueller-Dombois 1981). Subsequently, exclosures and 14 grassland transects were sampled for an additional six years (Stone et al. 1992; Pratt, unpublished data).

Before feral goats were excluded from the Mauna Loa Strip, the recovery of koa was monitored inside a goat exclosure (Spatz and Mueller-Dombois 1972, 1973). Feral goats were removed from units of the Mauna Loa SEA in 1985 (Katahira et al. 1993). Recovery of montane koa forest vegetation was monitored using 20 pairs of plots above and below an exclusionary fence at 2,070 m (6,800 ft) elevation (Stone et al. 1992; Tunison, unpublished data). Another set of vegetation plots was systematically placed along transects between Kipuka Ki and the upper fence in the mid 1980s (Tunison and Pratt, unpublished data). Three transects monitored recovery of native grasses and shrubs in Kipuka Maunaiu and Kipuka Kulalio above and below the upper fence (Stone et al. 1992; Pratt, unpublished data). Recently mouflon sheep have invaded the subalpine and montane forest of the Mauna Loa Strip. One rare plant monitoring study demonstrated serious damage to a threatened plant species (Silene hawaiiensis) caused by mouflon (Belfield and Pratt 2002). Two tagged populations of Silene could serve as long-term monitoring for recovery of the rare plant. Another Silene population inside and outside a razor-wire exclosure was monitored for a year and could function as a baseline for future monitoring.

The most damaging feral ungulate in HAVO rain forests is the pig. Numerous studies have focused on the impacts of this destructive alien animal on Hawaiian rain forests, and HAVO management units have provided data on recovery of forests after feral pig removal. Olaa Forest is the site of most studies of vegetation recovery after pig removal (Stone et al. 1992; Pratt and Abbott in prep.; Loh et al., unpublished data). One monitoring project was carried out for more than two years in forests of Kilauea`s East Rift (Pratt et al. 1999); the 29 pig-disturbed vegetation plots established for this study might be relocated for continued monitoring, although some of the plots were in forest that burned in June, 2003. Pig activity transects have been established within rain forests of both Olaa and the East Rift, and quarterly to annual surveys were undertaken between 1985 and 2003 (Stout et al. in prep.). Exclosures have been used to monitor rain forest recovery at several sites in HAVO, including Olaa, the East Rift, and the Fern Forest near Thurston Lava Tube (Higashino and Stone 1982; Loope and Scowcroft 1985). Feral pigs have also impacted dry and mesic forest vegetation of the Mauna Loa Strip. The effects of feral pigs on grassland succession were investigated by Spatz and Mueller-Dombois (1972). Changes in vegetation in pig-disturbed plots were monitored for seven years at several Mauna Loa Strip sites (Tunison et al. 1994).

3. HALE

HALE resource managers have been highly successful at removing feral goats and pigs from the park. Many monitoring projects established to determine vegetation trends may now be used to document recovery after feral animal removal. Monitoring of threatened Haleakala silverswords that has continued after removal of feral goats from Haleakala Crater provides information on population size of the rare plant (Loope and Crivellone 1986), although Kobayashi (1973) did not consider goat depredation a serious limiting factor of the species. Other vegetation monitoring projects within and near the Crater, such as quadrats at Puu Mamane and Sadleria cyatheoides plots at Halemauu Pali, provide information on recovery after removal of feral goats. Evaulation of an exclosure in the Crater between the Bottomless Pit and Paliku detected no reproduction of mamane (Sophora chrysophylla) after ten years of protection (Jacobi 1980). An exclosure on the west slope established to protect sandalwood (Santalum haleakalae) and mamane documented slow changes in native vegetation after exclusion of feral ungulates. Another exclosure in West Kaupo monitored changes in native shrubland with protection from goats (Medeiros et al. unpublished). Dry forests in and near HALE were the subjects of a rare plant survey (Medeiros et al. 1986). Those areas now free of feral animals might be re-surveyed for rare plants.

One exclosure in Kalapawili grasslands documented recovery following protection from feral pigs (Jacobi 1981). Other transects in the grasslands were used to monitor vegetation before and after exclusion of pigs and goats (Anderson et al. 1992, Medeiros unpublished data). Montane bogs fenced to exclude feral pigs were monitored for seven years by Loope et al. (1994); other unprotected bogs were also monitored Medeiros et al (1994). Earlier studies of HALE bogs are also available (Vogl and Henrickson 1969). The impacts of feral pigs on rain forests of Kipahulu Valley were studied by Diong (1983). Transects and vegetation plots established in the valley prior to removal of feral pigs may be used to demonstrate recovery of vegetation (Anderson et al. 1992; Anderson 1995; Medeiros et al. unpublished data). Data from the Forest Bird Survey more than twenty years ago may also document vegetation changes.

4. KALA

The vegetation of KALA is threatened by feral goats, pigs, and axis deer (Axis axis), although the latter species appears to be the most damaging to the park`s resources. Domestic cattle and horses (Equus caballus) have also recently inhabited the park (Canfield 1990b). Exclusionary fences have been constructed around Kauhako Crater and surrounding rare plants of the coastal strand. Currently, park staff members are cooperating with Hawaii State DLNR, The Nature Conservancy, and Kamehameha Schools to carry out joint fencing projects in upslope rain forest that will benefit the park and other conservation lands. Baseline monitoring of ground and canopy cover within the dry forest of Kauhako Crater was initiated in 1995, prior to fencing and removal of feral ungulates (Medeiros et al. 1996). This community-level monitoring, as well as measurements and evaluation of rare tree species, may be replicated in the future as part of a vegetation recovery project. Canfield (1990) recommended that several exclosures be constructed to protect different plant associations of strand vegetation to determine the impacts of domestic and feral animals on both native and alien plants of the coastal vegetation.

5. PUHO, KAHO, PUHE, and ALKA

At present, the three Kona Historical Parks have no feral ungulate populations within their lands. However, portions of all three parks were formerly used to graze cattle and goats. PUHO has a boundary fence to keep out domestic cattle and feral sheep. Feral pigs have damged wetlands at KAHO in the recent past, but managers were able to remove the animals. Grazing animals are excluded from PUHE by ranch fences upslope of the park. The status of feral ungulates along the trail of ALKA is currently unknown.

6. AMME and WAPA

AMME on the island of Saipan does not have feral ungulate populations or shared boundaries with areas supporting domestic cattle. Feral cats and dogs may be present, however. The small park is adjacent to a town (Garapan) and the ocean (Raulerson and Rinehart 1989). WAPA on the island of Guam undoubtedly has populations of feral pigs and Philippine deer (Cervus mariannus) living within some of its units. Carabao or water buffalo (Bubalus bubalis) may also inhabit some of the ravine vegetation adjacent to river systems within the park. No monitoring of feral animal impacts has been done within the units of WAPA, and no vegetation recovery studies are underway.

7. NPSA

NPSA units support populations of feral pigs, an ungulate species that was introduced to Samoa thousands of years ago by Polynesian settlers. Whistler (1994) considered feral pigs to be a problem in the Tutuila unit. Before hunting declined, pig population levels were reduced by local hunters. Feral pigs are also a pest on Tau, where they damage cultivated crops, leading to abandonment of upper-elevation fields (Whistler 1992). Park staff members are currently monitoring pig activity transects, at least on Tutuila (Stassia Samuels, pers. comm.).

E. Alien Rodents:

1. HAVO

Rats and mice are not native to the Hawaiian Islands, although the Polynesian rat (Rattus exulans) was an early arrival with the Hawaiian people. The black or roof rat (Rattus rattus), in particular, has been implicated as a seed predator and consumer of many native plant species (Stone 1985). The distribution of rodents was monitored along several elevational transects on Mauna Loa as part of the International Biological Program (IBP) in HAVO (Tomich 1981). Distribution, density, population composition, and food habits of rats were monitored in several SEAs of HAVO in the late 1980s. A preliminary study of the use of toxicants to temporarily reduce rats in a mesic forest was also made (Forbes and Stone 1997; Stone unpublished data 1986-1990). Recently out-planted seedlings and trays of native seeds were monitored for two years as part of a small mammal toxicant project (Foote and Pratt, unpublished data). Vegetation in the wet and mesic forest study areas was monitored before and after the toxicant study. Food habit studies of introduced rats have also provided information on consumption of native plants and seed predation (Russell 1980). Rats are seed predators of both common and rare plant species in the park (Baker 1979; Male and Loeffler 1997).

2. HALE

Monitoring of rat populations was also carried out in HALE in 1983-84 as part of the Kipahulu Interdisclipinary Study (Stone et al. 1984). Rodent food habit studies were accomplished at HALE, and reductions of native arthropods were demonstrated. Few direct impacts on native plants were documented, although seed predation by rats was observed (Cole et al. 2000). Sugihara (1997) studied rat populations and food habits in Hanawi Natural Area Reserve, adjacent to HALE. Data on rat predation are collected in current HALE rare plant monitoring programs. Additional monitoring of the impacts of rats on rare plant populations in both HALE and HAVO is warranted.

3. KALA

No rodent monitoring has been carried out at KALA, but Medeiros et al. 1996 recommended studies to determine the impacts of rodents on rare tree species at Kauhako Crater.

4. KAHO, PUHO, PUHE and ALKA

Assessment of rodent and mongoose populations was part of a monitoring project in all three of the Kona Historical Parks, but the impacts of rats on native plants was not part of the study (Stone, unpublished data 1992-1994). Even though the vegetation of the three Kona Parks (KAHO, PUHO, PUHE) is largely alien, rodents may be impacting large-seeded native species in the parks. Plants suffering from rodent seed predation likely include naio (Myoporum sandwicense), pua pilo (Capparis sandwichiana, a species of concern), and the endangered loulu palm (Pritchardia affinis).

5. AMME, WAPA, and NPSA

Rodents are not native to Guam or Saipan, and their impacts on the vegetation resources of AMME and WAPA are currently unknown. American Samoa also has alien rat populations, and there have been no studies to date on the impacts of rats on native plants of NPSA. However, data from native tree monitoring established within the Tutuila unit by Whistler (1994) and Heggie and Cairns (2001) may possibly contribute to a program to monitor rat impacts on native tree species, as both projects collected stand structure data. Those tree species with large seeds are most at risk from introduced rodents.

F. Fire Effects Monitoring:

Most of the fire effects monitoring in the network has taken place at HAVO. Fire frequency is high at HAVO because of the prevalence of available fuels, high visitation, and lava flow ignition sources. Fire effects monitoring has been established largely in the coastal lowland shrublands and grasslands and in the dry ohia woodlands. The results of these monitoring efforts from the 1980s have been summarized in PCSU Technical Reports (Tunison et al. 1994, 1995). In 2002-03, monitoring was established prior to prescribed burning for native plant restoration in both of these communities. Monitoring has also been established in uluhe (Dicranopteris linearis)-dominated rain forest, and montane seasonal koa forest and native shrublands, from the mid-1980s to 2003. Additional monitoring is being established in mesic ohia forest and uluhe rain forest in 2003. The focus of the monitoring effort at HAVO has been plant population and community changes over time following wild fire or prescribed burning. Changes in the status of soil nitrogen have been evaluated in several burns on a one-time basis and may be amenable to long- term monitoring. HALE has had only one fire in the last several decades, in 1993; that small burn is being monitored for vegetation changes. Monitoring transects were established in PUHE in 1990 and portions of those areas may have burned in large regional grass fires that have encroached on the park. Localized debris burns of dead, piled kiawe (Prosopis pallida) have taken place in the last decade but no monitoring has been done. Small, prescribed burns are being monitored at PUHE in an effort to understand the relationship of exotic and native grasses and establish native pili grass (Heteropogon contortus). A small, prescribed burn was conducted adjacent to the parking lot at PUHO Visitor Center for similar purposes. Fires at KAHO have been limited to debris burning to remove kiawe; no monitoring has been associated with kiawe burning. WAPA has a relatively high frequency of fire, but no monitoring has been carried out. A research project has been recently initiated to study fire and erosion in savanna vegetation. No fires have occurred at KALA, NPSA, or AMME.

G. Restoration and Re-introduction of Native Plants.

1. HAVO

HAVO has begun restoration or rehabilitation of fire-damaged communities in the coastal lowlands, dry ohia woodlands, and mesic ohia forest using out-plantings and seed sowing. Experimental vegetation rehabilitation is underway in dry ohia woodland damaged by alien insects, as well as in disturbed montane koa forest and soapberry savanna altered by years of cattle grazing. Out-plantings are monitored for survivorship, and direct seeding sites are monitored for germination, growth, and reproduction. In addition, rehabilitation sites are monitored on a community scale for diversity, cover, and density of plant species. Rare plant species are being re-introduced or augmented as part of a rare plant stabilization project in the subalpine, montane mesic forest, montane rain forest, lowland dry forest, and coastal strand. Rare plant restoration projects are monitored for mortality, growth, and reproduction on an annual basis. A large-scale, multi-year project to introduce the Mauna Loa silversword (Argyroxiphium kauense) to HAVO involves annual monitoring of mortality and growth of a sub-set of more than 8,000 out-planted individuals and a goal of 12,500 plants (Tunison 2003).

2. HALE

HALE began restoring dry forests and shrublands in East Kaupo in 1995 by eliminating the mat-forming kikuyu grass (Pennisetum clandestinum) and outplanting seedlings of both common and rare species; this restoration effort is ongoing. Outplanting has been initiated in the central part of Haleakala Crater, and expansion of this program is planned. A program to stabilize and augment rare plant populations within the park was begun in 2000, and many endangered and rare species have been propagated and outplanted. This long-term project will involve a monitoring component. Previous survey and inventory work on the south slope of Haleakala (Medeiros et al. 1986), as well as studies of montane bogs (Loope et al 1991; Medeiros et al. 1991) and Kipahulu Valley rain forest (Lamoureux in Warner 1967; Anderson et al. unpublished; Medeiros et al. unpublished) will be invaluable for determining rare species re-introduction goals. The recent HALE flowering plant checklist (Medeiros et al. 1998) contains much information on rare plant collections and distributions within the park.

3. KALA

KALA has a native plant restoration project ongoing for coastal Pritchardia hillebrandii forest (G. Hughes pers. comm.), and exclosures have been placed in coastal strand communities for restoration and monitoring purposes. Inventory and monitoring of offshore islets have provided information on native species composition that may be used in future coastal restoration projects (Wood and LeGrande 2002). Recommendations of species deserving of re-introduction or augmentation have been made for Kauhako Crater (Medeiros et al. 1996), a dry to mesic forest recently fenced in preparation for a restoration effort. Feral ungulates are being removed from a section of the Puu Alii plateau, and some restoration efforts may be required for this rain forest.

4. PUHO, PUHE, and KAHO

PUHO and PUHE have introduced native plants to developed areas near buildings, but these landscape out-plantings have not been monitored. As part of future landscape restoration projects, both parks may re-introduce native plant species likely to have occurred in leeward coastal habitats. KAHO has begun a program of re-introducing native dryland coastal plant species, including the candidate endangered ko`oko`olau Bidens micrantha subsp. ctenophylla. This restoration project includes augmentation of uncommon species from plant stock within the park, as well as introduction of species no longer found in KAHO but recommended for re-introduction by the Vegetation Management Plan (Pratt 1998). Additional native plants known from the park or identified in the pollen record may soon be introduced to areas where alien plants are removed (Stan Bond pers. comm.). Some pollen analysis has been done for Aimakapa Pond (Douglas and Hotchkiss 1998), and further research is planned. Pollen cores from additonal ponds and pools may be used to identify native plants formerly growing in or near the park. Work on pollen assemblages of the Hawaiian Islands may lead to increased knowledge of past natural vegetation prior to human disturbance (Hotchkiss and Douglas 1998).

5. AMME, WAPA, and NPSA

AMME, WAPA, and NPSA have no current native plant re-introduction projects. Raulerson and Rinehart (1989) suggested the introduction of palo maria (Calophyllum inophyllum) to the coast at AMME to stabilize the jetty and shoreline picnic areas. Native strand plants were proposed for use in landscaping near the Headquarters of WAPA, but the recent typhoon destroyed the building. Re-introduction of native plants may be considered for eroded savanna following a planned research project on recovery of savanna communities after fire (Dwayne Minton pers. comm.). Several projects involving re-introduction of native strand plants and restoration of historic vegetation to coastal units of WAPA were proposed after Supertyphoon Paka, but none was funded (Anderson, unpublished 1999). Recently, a proposal was developed to restore native tree species to Alava Ridge, an area disturbed by past road-building and agriculture within the Tutuila unit of NPSA (Monella, unpublished 2003b).

H. Long-term Vegetation Monitoring.

Long-term monitoring is perhaps the most important type of monitoring project for the purpose of answering questions about the stability of ecosystems and the effects of management activities in the National Park. Such projects are also the least common and most expensive of monitoring programs. The importance of National Parks and other natural areas for environmental monitoring was described by Moir (1972). "The idea of natural areas as environmental monitoring systems stems from their use as controls or bench marks. Ecosystems in their more or less natural state are measured for predictive purposes against similar ecosystems that have been altered by man." The long-term monitoring data sets identified below are a sampling of known vegetation monitoring projects that might be continued or repeated to provide guidance to managers.

HAVO is the site of numerous past and current research and management projects involving vegetation monitoring. Many of these, particularly weed and rare plant monitoring in SEAs (Abbott and Pratt 1996; Pratt and Abbott 1997; Pratt, unpublished data) and rare plant population monitoring throughout the park, could be useful to managers if they were continued in the future. Permanent transects and plots associated with research projects of the recent past could be monitored to answer questions about long-term change in wet and mesic forests; the Rare Plant and Invertebrate Project (RPIP) is notable for forty large vegetation plots in which stand structure, tree density, and ground cover were measured (Foote and Pratt, unpublished data.). Several exclosures built within the park to determine impacts of alien ungulates have been in place for several decades, and these structures and associated data sets are extremely valuable for detecting long-term trends (Loope and Scowcroft 1985). One vegetation research project begun 25 years ago, the ohia rain forest or dieback study (Mueller-Dombois 1974, 1977; Mueller-Dombois et al. 1980), has six vegetation plots sited within the Olaa Forest and several others in forests of Kilauea. These HAVO vegetation plots have been re-monitored several times (Jacobi et al. 1984, 1988), and have been recently relocated and retagged as part of a new analysis of changes in vegetation over time (Boehmer in prep.). Some of the permanent ohia dieback plots were also used to study nutrient limitations (Gerrish et al. 1988) and growth of ohia (Gerrish and Mueller-Dombois 1999). Vegetation data collected along elevational transects during the International Biological Program (Mueller-Dombois et al. 1981) may also be valuable for long-term studies of the vegetation of HAVO. The great variation in substrate ages and the continuing activity of volcanoes in HAVO provide a framework for monitoring vegetation in a successional context. At least one earlier study established permanent transects for studying succession in HAVO (Smathers and Mueller-Dombois 1974).

Long-term monitoring has not been established in all the vegetation types of HAVO; such a program would enhance the park's ability to detect change in vegetation over time. The subject of plant diseases and their impacts on native vegetation is one that deserves a monitoring project. The geographical extent, severity, and long-term implications of koa wilt disease (Anderson et al. 2001) and Dodonaea yellows remain little understood in HAVO.

Sites within HAVO have been used for more than a decade to study nutrient cycling in montane rain forests, and data from the geologically young park sites (particularly near Thurston Lava Tube) have been compared with that of older sites on Hawaii and other islands as part of research along a substrate age gradient (Hobbie and Vitousek 2000; Crews et al. 1995; Riley and Vitousek 1995). Recently, nitrogen fixation in bryophytes, lichens, and wood was studied at park sites in Olaa and Thurston forests and compared with older sites in the soil-age gradient

(Matzek and Vitousek 2003). Nutrient limitation during primary succession has been studied at a site near Devastation Trail in HAVO (Vitousek et al. 1993).

HALE has long-term data sets for the Haleakala silversword (Argyroxiphium sandwicensis var. macrocephalum) in the Crater District. Other vegetation plots established on Puu Mamane, Halemauu Pali, Kalapawili grasslands, and West Kaupo may also be baseline data sets for future monitoring (Loope and Medeiros, unpublished). Monitoring of na`ena`e (Dubautia menziesii) in the Crater and sandalwood (Santalum haleakalae) and dry shrublands inside and outside 10-20 year old exclosures on the West Slope may be important for long-term studies. Vegetation recovery and degradation in bogs of the park were monitored for much of the 1980s (Loope et al 1991; Medeiros et al. 1991), and these sites were recently re-visited by Hotchkiss and Werner (in prep.). This new effort to continue montane bog monitoring creates a long-term data set for this rare vegetation type. In Kipahulu Valley, there are permanent transects with weed data, rare plant data, and vegetation plots in which cover and density were measured (Anderson et al.1992; Medeiros unpublished). Hotchkiss (in prep.) has recently re-sampled vegetation near the treeline of Haleakala; thus building on previous vegetation monitoring efforts and creating a long-term data set for the area; climate data is also being collected along an elevational gradient at HALE. A number of exclosures have been constructed in and near HALE over the last several decades (Loope and Scowcroft 1985), and these should be part of any long-term monitoring program. One transect established by Kitayama and Mueller-Dombois (1992) passed through the upper reaches of HALE and a large number of releves were used to sample vegetation in three elevational zones. These data on composition and structure of plant communities of the montane and high-altitude zones of windward Haleakala may provide a useful baseline for vegetation monitoring in the park.

Both HAVO and HALE were part of the study area for the Forest Bird Survey (Scott et al. 1986), and as part of the vegetation mapping component of this extensive, multi-island project, data on vegetation composition and cover were collected in plots every 150 m on transects at 2-mile intervals (Jacobi 1990, 1989). Transects have been relocated and flagged for subsequent bird surveys and vegetation plots at stations might be re-sampled as part of a long-term monitoring of park rain forests (and upland dry to mesic forests). The upper elevation forests of KALA were also part of the Forest Bird Survey study area. In addition, a baseline for rare plant population monitoring has been developed, at least for Kauhako Crater (Medeiros et al. 1996) and for two rare plant species of the coast.

The three Kona Historical Parks were inventoried for plants, birds and invertebrates in the 1990s. Baseline data on alien and native plant distributions and estimated abundance from systematic transects in PUHO and KAHO could be the basis for a long-term monitoring project (Pratt and Abbott 1996 a, 1996b), or more repeatable methods and permanently marked vegetation plots could be designed for this purpose. PUHE was not sampled systematically in the 1990s (Pratt and Abbott 1996c), but Macneil and Hemmes (1977) sampled roadside vegetation with quadrats on short transects, and these might be relocated or replicated for a long-term (>25 years) monitoring program. Recent research projects on fountain grass (Pennisetum setaceum) at KAHO (Williams et al. 1995) and pili grass (Heteropogon contortus) at PUHE (Daehler unpublished) may provide baseline information for long-term studies of alien and native grasses.

WAPA has no current long-term vegetation monitoring ongoing, but future studies within savanna vegetation may provide data for such monitoring. AMME has been monitored with four wetland transects (Raulerson and Rinehart 1989) that could be relocated and used for long-term studies. Vegetation of two NPSA units was studied by Whistler (1992, 1994), and his vegetation plots may be the basis for long-term monitoring of tree species. These plots are primarily in the Tutuila unit, and one was placed on Tau. Some of the vegetation plots were re-monitored in 2002 by Travis Heggie (Stassia Samuels, pers. comm.). Recently, Heggie and Cairns (2001) placed 85 vegetation plots within the National Park unit on Tutuila, as part of a larger classification of forest types on the island. Ofu has received only a plant species inventory (Whistler 1992), and the newly-designated Olosega unit has not been recently surveyed. The Department of Marine and Wildlife Resources (DMWR) has a tree phenology project that uses sites within the park. This ongoing monitoring of trees used by fruit bats may constitute a valuable long-term vegetation data set that also relates to human exploitation of the park's natural resources. One recent study investigated the nutritional quality of leaves and fruit consumed by fruit bats (or flying foxes) of Tutuila (Nelson et al. 2000).

I. Fragmentation and Adjacent Land Use

All the parks of the Pacific Network with vegetation resources exhibit some fragmentation of natural vegetation. HAVO and KAHO incorporate vegetation naturally fragmented by lava flows. Within HAVO there are large numbers of kipuka of all ages, surrounded by recent lava flows. These natural forest fragments contribute to vegetation diversity and provide seed sources for developing vegetation on young substrates. Past land use within HAVO has also led to fragmentation. Prehistoric burning and historic wildfires have left some less flammable pockets of vegetation surrounded by alien plants. Past ranching in a park inholding (Ainahou) has also contributed to fragmentation. Current use as ranches of lands on either side of the Mauna Loa Strip separates the recovering koa forest from similar habitat on both the east and west. The disjunct Olaa Tract is bordered on two sides by farming and grazing land, which partially fragments this large (ca 3,700 ha) block of montane rain forest and separates it from rain forest of the Kilauea summit. HALE is similarly bounded by ranchland and areas infested with feral goats, as well as Axis deer. Kipahulu Valley of HALE is less fragmented, because its upper reaches are bounded by a managed Natural Area Reserve and a TNC Preserve. However, little natural vegetation remains in lower Kipahulu, where native forest fragments are surrounded by a dense cover of alien plant species.

The three relatively small Historical Parks of Kona all have highly disturbed lowlands, ranches, or urban areas adjacent on three sides. The situation at PUHE is particularly egregious, as construction of the adjacent Kawaihae Harbor has completely transformed the natural seacoast of the area and dredged the sea floor. KAHO, PUHO, and PUHE may be considered terrestrial islands managed for natural values surrounded by highly modified lands. The peninsula upon which KALA is located naturally isolates the park, but some lands on the upper park boundary continue to be used as a cattle ranch. Because much of the KALA peninsula has been disturbed in the past, the natural vegetation of the lower part of the park is composed of relictual forests or native strand vegetation surrounded by alien plant cover. Only the higher-elevation portion of KALA supports an expanse of rain forest, which is bounded by TNC Preserves.

AMME is a small park that contains a fragment of native vegetation, as well as alien plant cover and developed areas. It has an urban interface on two sides. The units of WAPA are all small areas, in some cases surrounded by highly modified areas, former military structures, and portions of villages. NPSA Tutuila unit exists in close proximity to the city of Pago Pago, but the three other units of the park are on islands with little urban development. The use of adjacent lands for subsistence farming and potential encroachment of cultivation onto parklands are serious concerns at NPSA.

Monitoring of adjacent land use and changes in use would be very helpful to planners at all Pacific Network Parks. Research into the optimal size of natural protected areas might identify appropriate areas to intensively manage in parks without current vegetation management and help refine the size and number of SEAs in the larger two parks. The question of the value of few large reserves versus many small ones has been addressed for animal populations in mainland parks (White 1986), but still has not been satisfactorily resolved (Shafer 1990; Swartz 1999).

J. Widely Used Monitoring Methods

Many standard monitoring techniques have been used to measure vegetation in HAVO, HALE, and the other parks of the Pacific Network. Some past projects have used techniques of cover/abundance estimates to monitor vegetation, but these are most useful for vegetation classification and mapping (Mueller-Dombois and Ellenberg 1974). Frequency of occurrence data collected along transects are often used to describe the distribution of alien plant species within parks. Most recent monitoring projects have measured plant cover and density in randomly or systematically selected plots of different sizes. Rare plant distributions and abundance have been determined along belt transects. More recently Global Positioning Devices have been used for rare plant mapping. Rare plant population monitoring usually requires the marking, measurement, and periodic visitation of individual plants of the population. These methods and others are described in a recent manual of measuring and monitoring techniques for plant populations (Elzinga et al. 1998, 2001). Jacobi (2002) summarized different types of data commonly collected in natural resources monitoring programs, including presence/absence, population counts, frequency of plots, percentage of individuals by category, plant density, plant cover, and size measurements of individual plants.

Over the last two decades there have been attempts to standardize monitoring to make data more comparable among land management agencies in Hawaii. A notable attempt was initiated by The Nature Conservancy of Hawaii (TNCH); monitoring methods were developed to assess the biological resources and threats (such as feral animals) for TNCH Preserves and the State's Natural Area Reserves (Dunn 1992; Hawaii Heritage Program 1987). The TNCH Preserves and Watershed Partnerships in which TNCH participate all have monitoring plans and data sets from monitoring of vegetation, rare plants, weeds, and feral ungulates (C. Cory, pers. comm. 2002).

More recently monitoring plans have been developed for specific conservation areas to ensure adequate recovery of endangered plants. An example is the Makua Implementation Plan that is being developed for the Makua Military Reservation of the island of O`ahu (in prep.). This plan specifies monitoring protocols for composition and structure of vegetation, evaluation of alien plant control, assessment of native plant populations, determination of success of out-plantings of rare native species, and detection of phytosanitation breaches. Methods are also prescribed for surveys of rare plants and invasive plants. Monitoring is an element of all community restoration projects in HAVO and HAVO, and monitoring plans are presented as part of each project review. Other network parks will incorporate monitoring into their rare plant and community restoration project proposals and work plans.

Elzinga et al. 1998 stressed that management objectives should be clearly defined prior to the development of a monitoring program. Sampling objectives, including details of statistical tests to be used to determine change and level of statistical significance required, must also be addressed prior to monitoring. The sampling design and selection of data analysis methods are the most important steps in developing a monitoring program (Jacobi 2002).

The monitoring plans developed by other NPS networks should provide useful information for the Pacific Islands Network monitoring plan. Many issues of sampling techniques and statistical analyses are shared by most parks and are not specific to one natural area or set of resources. Nonetheless, the monitoring plan for vegetation of the Hawaiian and Pacific Islands must take into consideration the highly endemic flora of the islands and the existence of vegetation types, such as tropical rain forests, which are not representative of vegetation of mainland North America. The volcanic nature of most of the Pacific Islands Network Parks, the natural isolation of the islands, and the vulnerability of island ecosystems to alien plant and animals invasions are all characteristics that somewhat distinguish the parks of the network from those of the American mainland.

Summary

A. Critical Resources of Vegetation and Plants

1. General

Intact or native-dominated plant communities that are not protected outside the National Parks; threatened and endangered plant species.

2. AMME

A wetland containing both native and non-native plant species is the most significant vegetation resource of this small park. The wetland containing mangroves is a type rare in the Northern Marianas and provides habitat for the endangered Marianas subspecies of moorhen or gallinule (Gallinula choropus guami). The endangered Nightingale Reed Warbler (Acrocephalus lusinia) is also present.

3. WAPA

Limestone forest remnants, savanna vegetation recovering from fire, and riverine forests are significant vegetation resources. The Asan Inland and Asan Beach units comprise an entire sub-watershed and may provide significant opportunities for ecological research.

4. NPSA

Montane rain forest and summit scrub is most vulnerable on Tutuila, and the lowland Dysoxylum samoense rain forest is a critical resource of Tau. All other native vegetation types in the park are important, as they are unique among NPS units. Rare plant species need to be identified and protected; none is currently listed as endangered. Native fruit-bearing tree species are important as food sources for rare fruit bats (Pteropus samoensis, P. tonganus) and uncommon many-colored fruit doves (Ptilinopus perousii). Plants of ethnobotanical importance are also potential monitoring subjects.

5. USAR.

There are no significant native vegetation resources, although a few native plants have been used to landscape the visitor center.

6. KALA.

The upper-elevation rain forests of Waikolu and Puu Alii, diverse dry forest in Kauhako Crater, coastal strand communities, coastal forest, and unusual relictual vegetation on offshore islets are important resources. There are several threatened and endangered species and species of concern found on the Kalaupapa Peninsula and offshore islets. The endangered Centaurium sebaeoides occurs within an exclosure and the threatened Tetramolopium rockii var. rockii is a component of one of the strand communities. Additional T & E plant species may be found on unsurveyed cliffs in or near the park. The rain forests of Puu Alii NAR support many threatened, endangered, and rare plant species.

7. HALE

Recovering alpine aeolian cinderland, subalpine grassland and shrubland, montane bogs, cloud forest, rain forest, mesic and dry srhublands and forests are notable for high native species diversity. The protected rain forests of Kipahulu Valley, a research natural area and scientific reserve, are particularly important. Subalpine lakes and riparian habitat of perennial streams are valuable resources. The park supports at least 15 threatened and endangered plant species, 11 candidate endangered species, approximately 22 species of concern and almost 30 rare plant species; additional species within these categories are thought to have been extirpated from HALE.

8. PUHE

Native plant resources are concentrated in the strand and small wetland community. Experimental areas in which pili grass (Heteropogon contortus) is being restored are important to future restoration efforts. A population of the rare fern Ophioglossum polyphyllum persists in the park.

9. KAHO

The wetlands surrounding the two large fishponds are significant examples of much depleted plant communities. Coastal strand and areas around anchialine pools also support native plant species. The park supports a large population of the species of concern Capparis sandwichiana and smaller numbers of a candidate endangered species and a second SOC.

10. PUHO

Coastal strand and marsh surrounding anchialine pools support largely native vegetation. Other native plants are found scattered in alien plant-dominated vegetation. One species of concern and several uncommon lowland plant species are known from the park. Endangered loulu palms (Pritchardia affinis) have been planted near the Visitor Center. The detached upland garden has out-plantings of several endangered plant species native to Hawaii Island.

11. HAVO

Diverse mesic forests and rain forests of both Mauna Loa and Kilauea East Rift; upper montane, subalpine and alpine communities; relictual dry forests; lowland ecosystems proposed for restoration; beach and strand communities, anchialine ponds; and early successional lava flows and kipuka are significant vegetation resources. There are 22 threatened and endangered plant species, 5 candidates for endangered status, 22 species of concern, and 40 rare plant species known from the park; this includes several extirpated and extinct species. Native plant species and communities are of cultural significance in the context of traditional gathering.

12. ALKA

The vegetation resources of the newly designated Ala Kahakai Trail have not been inventoried.

B. Stressors on Vegetation and Flora

1. General/common stressors

Alien species invasions; visitor impacts in sensitive areas; effects of nearby development; contamination; type of management in areas surrounding parks including introduction of new species; loss of key ecosystem components; loss of biodiversity (listed by many parks but really a result, not a cause); and potential losses due to natural causes such as lava flows or climate change.

2. AMME

Visitor impacts in sensitive areas, including past turf removal and dumping in the wetland; encroaching development from the adjacent town; newly invasive plants such as ivy gourd (Coccinia grandis).

3. WAPA

Wildfire and subsequent erosion, particularly in savanna vegetation; adjacent incompatible development; invasive ungulates (feral pigs, Philippine deer) and alien plants; typhoons that repeatedly disturb vegetation cover, particularly in limestone forest.

4. NPSA

Expanding subsistence agriculture into forest, invasive alien plants and animals (feral pigs, rats, ants, etc); diseases. Potential stressors are new invasive alien species, climate change, hurricanes, incompatible tourism-related development on adjacent lands, and human population growth that leads to loss of habitat for native species.

5. USAR

There are no vegetation resources associated with this park.

6. KALA

Human impacts on offshore islands; invasive alien plants and animals (ungulates, rats, mosquitoes, ants); diseases; loss of biodiversity. Potential stressors are altered disturbance and succession regimes and new invasive alien plants and animals.

7. HALE

Alien plants and animals (feral pig, feral goat, axis deer, rats, ants, mosquitoes, trespass cattle), diseases, potential new introductions, visitor impacts in alpine zone, loss of key species (insect hosts, plant dispersers and pollinators), and potential wildfires.

8. PUHE

Invasive alien plant species, particularly kiawe (Prosopis pallida), puncture vine (Tribulus terrestris), fountain grass (Pennisetum setaceum), alien trees, shrubs, and vines that may damage cultural resources, and pickleweed (Batis maritima) recently removed from the coastal wetland; fire, erosion, in-park development. Potential stressors are development of a liquid-fuel storage facility adjacent to the park; resource damage from fuel spills and increased visitation from adjacent Kawaihae Harbor; damage from dirt bikes using the coral flats and stream bank.

9. KAHO

Development of coastal lands near the park; alien vegetation, erosion of sandy shoreline; invasive alien ungulates; rats, ants; loss of biodiversity; visitor impacts to natural resources. Potential stressors are the rise of sea level due to global warming, expansion of the adjacent Honokohau Harbor, additional development of mauka lands, increased visitation, and invasion of new alien plants and animals.

10. PUHO

Erosion of coastal areas, particularly with rising sea level due to global warming; incompatible development encroaching on park; invasive alien plants, including those already established (Leucaena leucocephala and Pithecellobium dulce) and invaders not yet in the park (ivy gourd or Coccinia grandis).

11. HAVO

Feral ungulates; invasive alien plants; rats; yellow jacket wasps (Vespula pensylvanica); mosquitoes; ants; diseases; loss of pollinators; small population size of native organisms and loss of endemic plant and animal species; change in nutrient, soil water, and fire regimes; wildfire; lava flows and volcanic emissions; incompatible uses in adjacent lands; park development; visitor impacts.

12. ALKA

Stressors are unknown at this time; surveys and evaluation of vegetation resources are necessary.

C. Monitoring Needs

1. General

2. AMME

Wetland community monitoring (baseline monitoring was accomplished in FY02); vegetation/habitat requirements of rare wetland bird species.

3. WAPA

Fire effects and erosion in savanna vegetation; impacts of feral ungulates and alien plant species; changes in limestone forest composition and cover.

4. NPSA

Rain forest ecosystem health; expansion of subsistence farming and effects of human disturbance; ungulate impacts on native vegetation; alien plant distribution monitoring; effectiveness of weed treatment and ungulate removal; population trends of rare plants (once they are defined).

5. USAR

No vegetation monitoring needs.

6. KALA

Rain forest, dry forest, and strand community recovery after feral deer and pig removal; rare plant population monitoring; vegetation mapping at a scale that shows native vegetation fragments and patch size; rain forest boundary mapping.

7. HALE

Rare plant population monitoring; alien plant distribution monitoring, including incipient invaders; continued treatment effectiveness monitoring in areas receiving alien plant control, feral ungulate removal, and restoration of native vegetation; recovery of significant plant communities; long-term changes in rain forests, diverse mesic forests, and upper montane, subalpine, and alpine ecosystems.

8. PUHE

Treatment effectiveness monitoring of areas converted from alien vegetation to pili grassland; monitoring of population of the rare pololei fern (Ophioglossum polyphyllum); monitoring of re-introduced native plants and restored communities.

9. KAHO

Wetland community monitoring; monitoring of both native and alien plants invading anchialine pools and causing senescence and infilling; native tree and shrub population monitoring; effectiveness of native plant introduction or re-introduction in alien plant removal areas; alien plant treatment effectiveness monitoring; rare plant population monitoring.

10. PUHO

Population monitoring of selected native and Polynesian plant species; community-level monitoring of coastal strand and wetland vegetation; effects of alien plant treatment and native plant re-introduction efforts (out-planting).

11. HAVO

Rare plant population monitoring; alien plant distribution monitoring, including incipient invaders; continued treatment effectiveness monitoring in areas receiving alien plant control, feral ungulate removal, and restoration of native vegetation; recovery of significant plant communities; impacts of cultural collecting on the population or community level; effects of fire; long-term changes in rain forests, diverse mesic forests, and upper montane, subalpine and alpine ecosystems; early succession on lava flows and kipuka complexes.

12. ALKA

Monitoring needs are currently unknown.

D. Research Needs

In general, protocols are in place for monitoring rare plant populations, alien plants, recovery after feral animals and fires, and vegetation community monitoring. Many past and current monitoring projects exist for HAVO and HALE, and to a lesser extent in the Kona Historical Parks. Little monitoring or vegetation research has been carried out in the parks of the Western and South Pacific. Research may be needed to develop statistically valid monitoring protocols applicable to a wide range of plant communities, populations, environments, and sampling questions. These may involve pilot studies to determine proper sample size and monitoring design. Past sampling methods and design varied wildly. Many environments have not been adequately sampled; vegetation of some parks and park units has not been systematically sampled at all. Monitoring methods in the past were developed piece-meal to answer specific monitoring questions. Pilot studies were rarely conducted.

Research to identify indicator species may be needed to develop efficient monitoring programs in many environments of the parks. Rare plant limiting factors research may help refine monitoring programs focused on rare plant populations, particularly in the large parks, which contain numerous rare and sensitive plant species. Weed species biology is largely unknown, even for species being controlled in large segments of the parks. More research into weed species life histories, phenology, seed production, seed dispersal, and seed banks would provide data useful for refinement of alien plant control and containment strategies in the network parks. Priority should be given to alien plant species that are present or potential threats to more than one park unit.

Appendix A: Data Mining Sources

A. Federal

1. NPS
2. USGS-BRD-PIERC
3. U. S. Forest Service
4. U. S. Fish and Wildlife Service

B. State/Territory

1. State of Hawaii Department of Land and Natural Resources
2. Division of Forestry and Wildlife and Natural Area Reserve System
3. Territory of American Samoa
4. Territory of Guam (Government of Guam)
5. Commonwealth of the Northern Marianas Islands

C. Non-Government Sources

1. Large Land Owners, particularly Kamehameha Schools/Bishop Estate
2. The Nature Conservancy of Hawaii
3. University of Hawaii at Manoa Botany and Biology Departments
4. University of Hawaii, Ecology & Evolution Program (including former Heritage Program)
5. University of Guam
6. Stanford University
7. University of California at Berkeley

Appendix B: Literature Review and Literature Cited.

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Appendix C: Workgroup Membership

Water Quality Workgroup Overview

Kimber DeVerse, Facilitator
Eva DiDonato, Workgroup Lead

These materials are currently in DRAFT form (as of 3/5/04). The authors have been asked to share these reports for comment in March 2004. In several cases, authors have only had several weeks to work on these materials, and this may be evident in the content of the report. Accordingly, we hope that comments can focus on helping us ensure we have identified the breadth and significance of natural resource and ecological issues in the Pacific Island Network.

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Introduction

The Water Quality Workgroup for the Pacific Island Network (PACN) was organized in August, 2002, and tasked with developing a water quality monitoring program for the PACN (Appendix A: Workgroup Membership). Although this program is primarily funded through National Park Service Water Resources Division (NPS-WRD), it is to be developed along side the NPS National Inventory and Monitoring Program. Several NPS documents are being used to guide our process (http://science.nature.nps.gov/im/monitor/protocols/wqPartB.doc, and http://science.nature.nps.gov/im/monitor/vsmTG.htm).

A. Definition of Topic Area

Water quality, as addressed by this workgroup, includes the status of freshwater, marine, and groundwater water quality. These water bodies include streams, lakes, wetlands, fish ponds, anchialine pools, tide pools, coastal, and interstitial waters. Aquatic issues that may be addressed include not only water column quality, but also habitat quality measures, sediment quality, pore water quality, bioaccumulation of toxins, and biological indicators such as invertebrate populations and primary production.

B. Monitoring Goals and Objectives

The overall goal of NPS water quality monitoring is to gather data that can be used to guide rational and responsible management actions and policies relating to the environment. The best scientific information needs to be readily available for resource managers to identify stressors and potential causes of change. Regular availability of monitoring results will help to alleviate public concerns or misconceptions, and provide justification for management guidelines and regulations. Without the proper measures in place, environmental stressors may not be detected or remedied until irreversible or catastrophic change has occurred.

A monitoring program for marine, brackish, freshwater, and groundwater will provide a system-wide understanding of the current status of water resources and enable informed management decisions when protecting resources from potential stressors. NPS natural resource managers are not the only ones who will benefit from this monitoring program. Education and conservation organizations can supplement their research and management programs with monitoring information and other community groups will benefit from the availability of credible scientific information about their valued resources. Regulatory and public health agencies are also interested in monitoring data that assists them in evaluating their respective environmental management concerns.

In the interest of collaboration, the water quality workgroup sponsored a planning meeting in which the monitoring plan and its purpose were considered. Discussion topics focused on park resource issues and values, monitoring objectives, desired future conditions and potential monitoring boundaries. Ideas generated from this process will be used in development of the monitoring plan (Appendix B: Contributors to the Meeting). A complete report of this meeting is available at http://www.nature.nps.gov/im/units/pacn/monitoring/plan/waterq/wq-mtg_20030812.doc.

The objectives for this monitoring plan are to:

- Summarize existing water quality issues at each park in the Pacific Island Network;
- Identify Outstanding National Resource Waters (ONRW) or impaired segments (or undesignated equivalents) as priorities for monitoring;
- Construct a Conceptual Model emphasizing common stresses among parks and identify common issues of concern throughout the network;
- Outline a strategy for long and short-term water quality monitoring in the Pacific Island Network.

C. Partnering

In the context of the larger network monitoring program, overlap between water quality and other subject areas have been identified. Especially critical is the link between water quality and the topics covered by the marine biology, freshwater biology, and geology work groups.

Although groundwater is typically handled through the geology workgroup nationwide, the obvious link in the islands between ground and surface water resources cannot be ignored (e.g. anchialine pond concerns focus on nutrients, oxygen, salinity, and ground water quantity inputs). Because of this, we will concern ourselves with groundwater quality and quantity where appropriate. It is essential to work closely with these and other work groups to gain an ecosystem-wide understanding of resource management challenges. Multiple lines of evidence will also better support management claims.

In addition to working with others in our agency, it is critical to work with other agencies that also have water quality goals and objectives. An extensive list of potential partners is being developed as information about current and past water quality studies is gathered (Appendix C: Potential partners).

Mandates and Legislation

The PACN monitoring program is rooted in a mixture of enabling legislation, the United States Code, executive orders, mandates and federal regulations. Some of these policies are specific to water quality such as the Service-wide Government Performance and Results Act (GPRA), the Clean Water Act (CWA), and Executive Order number 13089, which is an extension of the CWA pertaining to coral reefs. Mandates and legislation that the network's monitoring program is based on are listed at http://www.nature.nps.gov/im/monitor/#Legislation. Additional, information on park-enabling legislation can be found at http://www.nature.nps.gov/im/units/nw31/resources.htm

A. Inventory and Monitoring Program

The Inventory and Monitoring Program is part of the Natural Resource Challenge which places legislative emphasis on natural resource management through statistically sound monitoring and collaboration with other interested parties.

B. Federal and National Legislation

1. Service-wide Government Performance and Results Act(GPRA) goals (Strategic Plan 2001-2005)

The NPS has developed a framework for performance management that involves setting goals and measuring performance. In this plan, the water goal is listed as goal 1a4 which states, "85% of 265 Park units have unimpaired water quality". Little has been done in the Pacific Island Network parks with regards to water quality. Of that work, none has been long-term or consistent. A strong, cohesive water quality monitoring program will not only benefit each of the PACN park units, but will also allow us to understand the condition of our water resources to work towards GPRA goals.

2. Clean Water Act (CWA)

The Clean Water Act requires states/territories to identify and publish water quality standards, those waters that do not meet the adopted standards, and the ones not expected to meet the standards. All water bodies are included: fresh, marine, and estuarine. If water quality fails to comply with set standards, said waters are added to the state's "303d list". Once waters are listed, state and federal agencies are tasked with bringing waters back into compliance. As of the 2002 CWA 303d report by the US EPA, Pearl Harbor, the location of USAR, Pelekane Bay, offshore of PUHE, and Tanapag Harbor, adjacent to AMME, are the only PACN water bodies that have been identified as "impaired".

3. The Coastal Zone Act Reauthorization Amendments (CZARA) of 1990

The Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 mandates states with coastal waters to formulate management plans for non-point source pollution.

4. Executive Order 13089 for Coral Reef Protection 1998

This executive order is an extension of the CWA and other environmental statutes aimed at protecting coral reef ecosystems. It specifies that all federal agencies which may impact U.S. coral reef ecosystems identify their actions that do so, use their programs and personnel to "protect and enhance the conditions of such ecosystems," and to avoid degradation of coral reefs through their activities. The act further provides that "…Federal agencies whose actions affect U.S. coral reef ecosystems, shall…provide for implementation of measures needed to research, monitor, manage, and restore affected ecosystems…"

5. The Coral Reef Conservation Act of 2000 (16 U.S.C. §6401 et. seq.)

The Coral Reef Conservation Act provides matching funds to agencies conducting coral reef conservation projects in the United States. The overall purpose of this act is "to preserve, sustain, and restore the condition of coral reef ecosystems."

C. State and Territorial Legislation

1. Jurisdiction of Marine Areas

Administrative responsibility for marine areas varies depending on the local statutes. Within the State of Hawaii, the NPS does not have legal jurisdiction over marine resources, yet there is a management interest, especially in parks that include an authorized marine area. In the Territories of Guam and American Samoa, the NPS has management jurisdiction over some marine waters. NPS does not have any marine acreage nor management authority in CNMI, although on-going court cases may change this.

2. Water Quality Standards

Federal, State, and Territorial regulations on water quality standards provide a framework for determining whether a resource is degraded or pristine. Although Hawaii, American Samoa, Guam and Saipan are governed by different water quality standards through their respective federal or local Environmental Protection Agencies, in the PACN, water bodies are designated and protected for specific uses. Decisions made for this monitoring program are based on the current report of standards for each area (Hawaii-2000, American Samoa-1999, Guam-2003, and Saipan-2002).

3. Water Body Classification and Use Designations

Water body designations for PACN water resources are listed for each park in Appendix D. Several parks have unique and/or pristine water resources which could be considered as Outstanding National Water Resources (ONWR) but this classification has not been developed by governments in the region. The identification of impaired waters for 303d listing is limited by the shortage and small scope of existing monitoring programs and, although these programs are often state-based, territories and other affiliated nation-states are beginning to participate in the process of identifying these resources.

a. Hawai'i

Hawaii's surface and marine waters are classified according to their use by the Hawaii Department of Health under Hawaii Administrative Rules, Title 11, Ch. 54, 2000. Proposed changes to these standards are in the final stages for approval and adoption in 2004. Pristine coastal waters are protected by classification as AA "with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions" including zones of mixing which are allowed in Class A marine areas. Freshwater resources, including wetlands and anchialine pools, of national parks in Hawaii have some special protection as Class 1a waters prohibiting "any conduct which results in a demonstrable increase in levels of point or nonpoint source contamination." Marine bottom ecosystems are classified as I; to remain "in their natural pristine state with an absolute minimum of pollution from any human-induced source," or II; allowing alteration upon approval through the established permitting process.

b. American Samoa

Similar to Hawaii, American Samoa designates areas based on usage and are called "Special Management Areas," although, NPSA waters are not specifically protected above and beyond other waters in the territory. Marine waters are classified by their type, embayment, open coastal, or ocean waters, for which a designated use is described. At this time, only Pago Pago Harbor, an area not within NPS boundaries, has been designated as impaired by the American Samoa Environmental Protection Agency (ASEPA). The ASEPA water quality standards designate wetlands separately from surface waters which may be Class 1 or Class 2. Groundwaters are classified as 1G when potable and 2G if the natural salinity exceeds 10,000 mg/L.

c. Guam

Guam Environmental Protection Agency (GEPA) also has a classification system for water bodies based on "Designated Uses" and "Use Support Criteria" which amount to water quality standards. Marine waters are classified as M-1, M-2, or M-3, and freshwater as S-1, S-2, and S-3. Within NPS boundaries, marine waters are classified as M-2. This classification means that the waters are of "Good" quality, and the "Primary Designated Uses" are whole-body contact recreation, aquatic life protection and consumption. Inland waters for this park have been designated S-3 indicating the lowest quality for this resource. The Northern Guam Lens (NGL) aquifer has been listed as impaired as of the 2002 EPA CWA 303d report, although, the non-potable perimeter of the aquifer has been classified as G2 due to its increased salinity.

d. Saipan

Under the jurisdiction of the Commonwealth of the Northern Marianas (CNMI) Department of Environmental Quality (DEQ), Saipan has two classifications (AA and A) for marine waters, and two for fresh surface water (1 and 2). The coastal waters of AMME are considered Class A waters “protected for their recreational use and aesthetic enjoyment. Other uses are allowed as long as they are compatible with the protection and propagation of fish, shellfish, and wildlife, and recreation in and on these waters of a limited body contact nature.” Saipan Lagoon, adjacent to the West boundary of AMME, has been identified as impaired by the 220 EPA CWA 303d report. AMME fresh waters are class 1 carrying the objective of an absolute minimum of human influence and the prohibition of wastewater discharges and mixing zones for these waters. At this time, groundwater quality management zones are being developed to protect the island’s drinking water sources.

Context

A. Network-Wide Management Concerns

Three types of water resources are shared by all PACN parks; marine, freshwater (see Appendix E), and groundwater. Network-wide concerns for these resources include atmospheric deposition, changes in hydrology and climate, chemical and microbial contamination, organic enrichment, invasive species, erosion, and sedimentation. Natural disturbance events contribute to the transfer of sediment and chemicals from land into nearby streams, groundwater and marine resources. Urban expansion often affects the hydrology of nearby ecosystems by diversion of streams and withdrawal of groundwater. Human population growth alters the aquatic habitat physically when construction and recreation activities contribute to erosion, pollution, and the introduction of alien species. Chemicals from land-based sources enter groundwater via surface water connections possibly contaminating drinking water supplies and eventually coastal resources. In the circumstance of global climate change, solar radiation and ambient temperature affect water quantity and quality, and as a direct result, the well being of organisms living in impacted areas.

Each of the park units in PACN is unique in location and in stressors that affect their water resources but there are also many shared concerns. Increased visitor use accompanying human population growth contributes to loss of habitat buffers and subsequent degradation of water quality in all systems. Development of adjacent lands and watersheds and control of feral animals that degrade vegetation and accelerate erosion is a concern at all parks. Runoff from agricultural and urban development and sedimentation due to natural and man-made causes contribute to organic enrichment, bacterial and chemical contamination, and increased turbidity. These issues are aggravated by natural events such as fire, flood, and climate change. Marine waters are also threatened by chemical and sewage pollution from commercial ships, harbor operations, and recreational activities such as fishing, swimming, camping and boating. Freshwater, wetland and estuarine habitats are important biologically and are especially vulnerable due to their small size and low flow. Diversion of and discharge into streams affects groundwater, coastal resources such as anchialine pools and wetlands, as well as nearshore areas. Impacted stream water reaching the reef may inhibit natural stream fauna from repopulating streams after a juvenile marine stage. Groundwater quality and hydrology is of critical importance to both humans and ecological communities and is often the water resource impacted first by anthropogenic factors.

Information on local drivers and stressors to water quality was obtained from management personnel at each park as well as water quality experts in the island groups. Key drivers/stressors include:

- Land use – filling, population/urban development, industrial and individual wastewater systems, agriculture/animal production, feral animals, waste disposal, roads, and commercial shipping operations. introduction of alien aquatic species

- Weather and Climate – tropical storms, climate change, global warming.

- Recreation – fishing, boating/personal watercraft, SCUBA diving/snorkeling

B. Local Issues

Through surveys and other communications, each park has identified the stressors which are most threatening to their water resources. Unique PACN water bodies include sub-alpine lakes, wetlands, coastal and submerged springs, shoreline fishponds, tide pools, anchialine pools, and a crater lake. Systems can be impacted by invasive species, sedimentation, organic enrichment, and chemical run-off. These problems are accelerated with urban development and agricultural land-uses. Chemical and microbial contaminants from terrestrial sources leach into the groundwater and eventually into coastal resources such as anchialine pools and wetlands. Atmospheric deposition of chemicals and particulates may cause problems in sub-alpine lakes and anchialine pools. Since these water bodies may be unique to their park and have water quality issues due to specific stresses, research and monitoring requirements will need to be addressed individually.

1. Impaired Water Bodies

The following parks include water resources that have been identified as impaired on the 2002 US EPA CWA 303d report. It is assumed that monitoring programs will be implemented under the EPA TMDL program to address these impairments.

- WAPA: Agana Bay, Northern Guam Lens Aquifer
- AMME: Saipan Lagoon
- USAR: Pearl Harbor
- ALKA: Pelekane Bay, Spencer Park Beach, Hapuna Beach, Kailua Bay, Magic Sands Beach, and Kealakekua Bay
- PUHE: Pelekane Bay

2. Marine Habitats

All PACN parks have near shore reef communities that may be impacted by situations inside or outside of park boundaries. In general, most of the parks do not have jurisdiction over the reef areas they are mandated to protect. Marine waters are impacted by chemical pollution and sewage discharges from commercial ships and harbor operations. Recreational activities such as fishing, camping, boating, and swimming are commonly adjacent to reef areas. In addition, management of areas inland of park boundaries affects the marine environment. Almost all parks are susceptible to the effects of feral animals that degrade vegetation and accelerate erosion. Development of adjacent lands and watersheds is a concern at all parks.

Runoff from agricultural and urban development and sedimentation due to natural and man-made causes contribute to eutrophication, bacterial and chemical contamination, and increased turbidity. Human population growth contributes to loss of habitat buffers and subsequent degradation of water quality. The rising sea level, due to global warming, will contribute to shoreline erosion and sedimentation of the reef. In addition, coral bleaching, mortality and disease are occurring due to warming sea surface temperatures.

3. Park Specific Issues

Park specific issues other than the reef concerns covered above are identified here on a park-by-park basis.

a. AMME:

Additional reef concerns include seepage/runoff from a garbage dump up-current and a site where PCBs were "cleaned up." This is compounded by the barrier reef which constricts water flow into and out of the marine area. Wetlands are present in the inland corner of the park where encroaching development, illegal dumping (past and present), flooding, and groundwater contamination from sewage are major concerns.

b. WAPA

Sedimentation of the reefs in Guam is aggravated by fires that consume the vegetation upslope. There is a power plant down current of the parks with a submerged thermal discharge pipe. PCBs are leaching from the military installation on the Orote(?) Peninsula adjacent to the Agat unit. The Asan unit has wetlands which are susceptible to contamination from unsewered residential areas and flooding events which bring soil and agricultural runoff. Inland units are unexplored and/or inaccessible making characterization of water bodies difficult there.

c. NPSA

Due to the traditional communal land tenure in American Samoa, the park area is leased from surrounding villages. Subsistence use of the land and water resources is allowed contributing to erosion from agricultural use and contamination from sewage. In a few instances, the upper portion of a stream will be within NPSA boundaries, while the lower part flows through a village before entering the sea. Impacted stream water reaching the reef may inhibit natural stream fauna from repopulating streams after a juvenile marine stage. Streams are also degraded by feral pigs. Tide pools located at the shoreline are impacted by visitor use and climate change. In the Ofu unit of NPSA there is a closed dump site that continues to percolate water of unknown quality into the marine environment. There are temperature tolerant corals near the west end of this unit which are an especially valuable resource. The location and possible extension of a landing strip in this area is of great concern. Offshore of the Ta'u unit, there are giant, single coral heads of significant age which are invaluable to studies of climate and marine ecology.

d. USAR

This park is located in Pearl Harbor where industrial and agricultural pollution are long-standing issues which have contributed to the degradation of this estuary. The centerpiece of this park is a sunken ship which has remained relatively undisturbed in spite of the release of petroleum products from within the hull as it rusts away. The ship also contributes to the presence of heavy metals dissolved in the water column and deposited in the sediment.

e. KALA

Feral pigs, deer and cattle degrade stream resources in and around this park. This adds to the stresses caused by diversion and input due to agriculture and urban development. Village areas in the park may have issues with the leaching of untreated sewage and PCBs. There is a large, deep, water-filled crater unique to this park.

f. HALE

There are numerous freshwater streams in this park which also has coastal springs and a sub-alpine lake unique in this network.   Although it has a relatively small coastal shoreline, it has a very large watershed in which the streams and lake are threatened by encroaching development, feral animals, and alien species. Fishing and swimming are common in streams which enter the ocean. Stream diversion may be an issue as watershed partnerships affect management of this area.

g. PUHE

A recreational harbor exists adjacent to the park and a commercial shipping facility on the other side of that. A recreational park is located on the other side. These contribute to the likelihood that marine recreation activities such as fishing and diving will increase leading to a subsequent increase in fuel spills, pollution, and alteration of the substrate. Dirt biking along coral flats and stream beds, municipal and industrial wastewater discharges, residential and resort development, and land-based recreational activities all contribute to erosion and pollution of the near shore water. A stream originating upslope from the park is influenced by diversion, storm water runoff, and erosion of the top soil. There may also be a marsh area which is uncharacterized.

h. KAHO

There are numerous anchialine ponds, two fish ponds, and a large embayment in this park located down slope of a growing industrial area. Leaching from upslope cesspools and septic tanks and industrial development contributes to bacterial contamination and nutrient loading of these resources. A small boat harbor is located between park units and is a source of petroleum, heavy metals, and phosphates from wash water. The threat of sedimentation onto the coral reef is increased by pond restoration activities, erosion of the sandy shoreline, and dredging and/or expansion of the harbor. The rising sea level, due to global, warming will also contribute to erosion of the shoreline.

i. PUHO

Urban development up-slope from the park and the high level of tourism will negatively impact water quality of springs, fishponds, tide pools, and the near shore marine environment. There are inland ponds that are vulnerable to sedimentation and eutrophication. There is a submerged, natural discharge presumably through a lava tube which is unique to this park and could be a conduit for contaminants originating upslope. It is expected that the rising sea level, due to global, warming will eventually flood this low coastal park.

j. HAVO

There are no known streams or lakes located in this park which is primarily made up of relatively fresh volcanic flows. Although the coastal area is large, the man-made stressors are limited by the volcanic activity which is the main agent of change there. There are anchialine pools along the coastal section and wetlands or bogs in the forested Ola'a unit which have not been assessed.

Current Water Quality Programs at Pacific Island Network Parks

Various water quality studies are in progress or are being planned to assess conditions at or near PACN. Few of these programs involve long term monitoring plans and even fewer are comprehensive in scope. Most study areas are outside of park boundaries and may have only one sampling location. In general, these projects are specific to one resource issue; usually relating to human health conditions. The table in Appendix F gives an indication where monitoring information is lacking.

A. AMME

The Division of Environmental Quality (DEQ) (http://www.deq.gov.mp/) regulates water quality and contaminants and is the permitting agency for pollution control, sewage disposal and earth-moving activities. It monitors water quality and administers most of the federal clean water laws. They conduct weekly monitoring of enterococci, fecal coliform, and nutrients near the Hyatt sewage outfall into the ocean adjacent to the park. They also monitor runoff at a site adjacent to the park boundary and at a storm water discharge basin created to prevent pollution runoff into the area near Smiling Cove Marina.

The University of Guam, Water and Energy Resources Institute (WERI) (http://www.uog.edu/weri) conducts research projects on surface and groundwater quality, pesticide and heavy metal contamination, and soil run-off. WERI is involved with some water quality work in the Puerto Rico Mud Flats, located NE of the park, which is the site of a military dump that has recently been closed. This area could qualify as a superfund site.

Coastal Resource Management is involved with benthic studies.

A hydrological study of the AMME wetland has been funded by the USGS-WRD for FY05. This wetland has fresh water at the periphery and is saline in the center indicating some connection to the ocean. Still in the planning stages, USGS will be doing this work and may monitor the groundwater level and salinity.

B. WAPA

NPS-WAPA has started a watershed-level project monitoring sedimentation on the near shore reefs. The marine monitoring portion currently includes water temperature and photosynthetically active radiation (PAR), and will soon add coral recruitment, and percent cover analysis.

Guam Environmental Protection Agency (GEPA) (http://www.guamepa.govguam.net/programs/index.html) monitors recreational beach waters weekly for enterococci. Three sample locations are adjacent to WAPA units. One site is just north of the Asan Unit and the other two are to the North and South of the Agat Unit boundaries. GEPA is in the planning stages of a marine monitoring program that will be using EMAP, also still in the design process.

The area south of Orote Peninsula is monitored by the US Navy as part of remediation for the Orote dump. This monitoring program includes analysis of water, invertebrates and fish for PCBs, heavy metals, dioxins, ferro-cyanins, and chlorinated pesticides. The area is currently open to recreational swimming but closed for fishing.

The University of Guam, Water and Energy Resources Institute (WERI) (http://www.uog.edu/weri) conducts research projects on surface and groundwater quality, pesticide and heavy metal contamination, and soil run-off. They also analyze duplicate samples from the Navy's remediation program for the Orote Peninsula.

C. NPSA

The American Samoa Environmental Protection Agency (ASEPA) is currently monitoring streams in the territory based on a probabilistic design within a human impact framework. One of their pristine sites is located in NPSA (Fagatuitui). This stream is sampled monthly for temperature, dissolved oxygen, pH, sp conductivity, nutrients, bacteria and flow. Sampling started in April, 2003 and will continue for 1 year. At that time another round of streams will be chosen randomly which may include another site in NPSA.

The World Wildlife Fund (WWF) has received a grant through the Environmental Protection Agency to do climate change research in the territory. Two of their seven sites are located in NPSA (Vatia and Tafeu Cove). As part of the project, paired water quality samples are taken from the stream and coral reef. Parameters include: nutrients, Chl a, DOC, and CDOM. Sampling started in October, 2002 and will continue quarterly until June, 2004.

NPSA currently has long-term temperature loggers on the reef in Vatia and Ofu.

D. USAR

USGSs Curt Storlazzi, NPS-USARs Marshall Owens, and the Submerged Resources Centers Matt Russell deploy and recover two instruments to measure the physical and chemical environment around the USS Arizona Memorial. Beginning in November 2002, A Sontek Triton wave/tide gauge has been measuring the physical environment: current velocity and direction, tidal and wave action, including surface wind waves. Water temperature, salinity, pH, dissolved oxygen, and oxidation-reduction potential are monitored using a YSI 6600 Sonde multisensor. These instruments must be recovered to download monitoring data approximately every two months. The program is anticipated to end after 12 to 15 months of data collection.

The US Navy has several monitoring programs for its various industrial activities in Pearl Harbor. The analytical work is performed by the Navy Public Works Center Environmental Laboratory located in the Pearl Harbor Naval Complex. The outfall from Fort Kamehameha Wastewater Treatment Facility discharges near the mouth of Pearl Harbor and its mixing zone is monitored quarterly for temperature, ammonia, nitrate/nitrite, total nitrogen, total phosphorous, turbidity, chlorophyll a, salinity, dissolved oxygen, and pH. The effluent is monitored continuously for total residual chlorine, and daily determinations are made for 5-day BOD, total suspended solids, pH, settleable solids, and oil and grease. Monthly analyses are performed to monitor effluent levels of ammonia, nitrate/nitrite, total nitrogen, total phosphorous, 5-day BOD and total suspended solids percent removal, the heavy metals; cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc, and toxicity testing with C. dubia and T. gratilla.

After qualifying rainfall events, storm water runoff is monitored at eight industrial sites in and around the Pearl Harbor Naval Compound. Depending on the industrial activities in the drainage area being sampled, analytes may include aluminum, arsenic, cadmium, chromium, copper, total cyanide, iron, lead, magnesium, mercury, nickel, selenium, silver, titanium, zinc, MBAS, chemical oxygen demand, biological oxygen, demand total suspended solids, total dissolved solids, ammonia, nitrate/nitrite, total nitrogen, total kjeldahl nitrogen, total phosphorous, pH, specific conductance, oil and grease, total petroleum hydrocarbons (THP), THP as gasoline, THP as diesel, total fuel hydrocarbons, and 21 organic compounds.

E. KALA

No water quality monitoring is being done in this park at this time.

The framework for a cooperative monitoring system on an island level is in place through work with the federal Enterprise Community (EC) designation and implementation, and USDA NRCS Watershed Restoration Action Strategy for the south shore of Molokai.

F. HALE

USGS Water Resources has a stream gauge inside the park at Kipahulu monitoring its flow only.

No other water quality monitoring is being done in this park at this time.

G. ALKA

Mauna Kea Soil and Water Conservation District (MKSWD) is a watershed partnership that is monitoring stream dynamics and erosion upslope from the park. They have instigated changes in land use aimed at decreasing the impact of the cattle ranch, stream diversion and recent drought. Management partnerships have been developed with cattle ranches that include vegetative growth studies and water storage and distribution strategies that will aid in fire suppression. Other projects include precipitation, sediment and vegetative cover monitoring by University of Hawaii, Hilo staff and students. New rain gauges and check dams are being installed to monitor the watershed, and an automatic sampling device is ready to be implemented under a bridge over Makeahua Stream pending final approval from Hawaii State Department of Transportation. This device will automatically measure and store data on flow rate and turbidity upon flood events and at regular intervals when the stream is running. Another automatic sampler is planned for Makahuna Stream. MKSWD is actively involved in developing a useful monitoring plan for the marine area of Pelekane Bay.

Hawaii State Department of Health (DOH) monitors monthly for enterococci and C. perfringins using the membrane filtration method at Kawaihae Harbor, Spencer County Beach Park, Hapuna State Beach Park, two sites near Puako Bay, Anaehoomalo Bay, two sites at

Honokohau Harbor, two sites in Kailua Bay, “Banyans” surf spot, Disappearing Sands County Beach Park, Kahaluu County Beach Park, and Keauhou Bay. Portable meters are used at these collection sites to measure temperature, salinity, turbidity, dissolved oxygen, and percent dissolved oxygen. A one-time collection for water chemistry is planned for three sites in Pelekane Bay: one from the pond formed by the damming of Makeahua Stream, and two marine samples to the North and the South sides of the bay. Inorganic nutrients (nitrate/nitrite, ammonium, phosphate, and silicate), total nitrogen, total phosphorous, temperature, pH, salinity, dissolved oxygen, turbidity, and total suspended solids will be determined for these locations.

Biweekly bacteria testing is being conducted by AECOS lab at a man-made recreational pond inside a resort at Kaupulehu.

Natural Energy Laboratory of Hawaii Authority (NELHA) has an on-going water quality monitoring program at Keahole Point that was begun in 1982. Twenty-one groundwater monitoring wells are sampled monthly for temperature, pH, salinity, dissolved oxygen, fecal coliform, enterococci, total phosphorous, total nitrogen, and the inorganic nutrients; nitrate/nitrite, phosphate, ammonium, and silicate. Two anchialine ponds, two aquaculture outfalls, seven coastal locations and six offshore transects, surface and bottom, are monitored quarterly for the same parameters as the wells listed above with the addition of chlorophyll a and turbidity measurements.

Bacterial monitoring is also conducted on a saltwater swimming pool inside the Royal Sea Cliff Condominiums south of Kailua by AECOS.

The National Parks Service Inventory and Monitoring Program has initiated monitoring of the anchialine ponds which includes water quality.

H. PUHE

Mauna Kea Soil and Water Conservation District (MKSWD) is a watershed partnership that is monitoring stream dynamics and erosion upslope from the park. They have instigated changes in land use aimed at decreasing the impact of the cattle ranch, stream diversion and recent drought. Management partnerships have been developed with cattle ranches that include vegetative growth studies and water storage and distribution strategies that will aid in fire suppression. Other projects include precipitation, sediment and vegetative cover monitoring by University of Hawaii, Hilo staff and students. New rain gauges and check dams are being installed to monitor the watershed, and an automatic sampling device is ready to be implemented under a bridge over Makeahua Stream pending final approval from Hawaii State Department of Transportation. This device will automatically measure and store data on flow rate and turbidity upon flood events and at regular intervals when the stream is running. Another automatic sampler is planned for Makahuna Stream. MKSWD is actively involved in developing a useful monitoring plan for the marine area of Pelekane Bay.

Hawaii State Department of Health (DOH) monitors monthly for enterococci and C. perfringins using the membrane filtration method at Kawaihae Harbor to the North and Spencer State Beach Park adjacent to the South boundary. Portable meters are used at these collection sites to measure temperature, salinity, turbidity, dissolved oxygen, and percent dissolved oxygen. A one-time collection for water chemistry is planned for three sites in Pelekane Bay: one from the pond formed by the damming of Makeahua Stream, and two marine samples to the North and the South sides of the bay. Inorganic nutrients (nitrate/nitrite, ammonium, phosphate, and silicate), total nitrogen, total phosphorous, temperature, pH, salinity, dissolved oxygen, turbidity, and total suspended solids will be determined for these locations.

I. KAHO

A two-year project funded by NPS-WRD to monitor nutrient fluctuations in wells, anchialine pools, Kaloko Pond and Aimakapa Pond will be implemented in 2004. This project will perform dye tracer studies to determine the residence time of water in the pools and ponds and will collect samples to analyze for biologically available nitrogen and phosphorus in the groundwater. Salinity, dissolved oxygen, silica, chlorophyll a and other pigments will also be monitored.

KAHO staff and community groups will be removing invasive algae from Kaloko Pond and monitoring for changes in benthic biota and substrate.

The Natural Energy Laboratory of Hawaii Authority (NELHA) has an on-going water quality monitoring program at Keahole Point two miles North of Kaloko Pond that was begun in 1982. Twenty-one groundwater monitoring wells are sampled monthly for temperature, pH, salinity, dissolved oxygen, fecal coliform, enterococci, total phosphorous, total nitrogen, and the inorganic nutrients; nitrate/nitrite, phosphate, ammonium, and silicate. Two anchialine ponds, two aquaculture outfalls, seven coastal locations and six offshore transects, surface and bottom, are monitored quarterly for the same parameters as the wells listed above with the addition of chlorophyll a and turbidity measurements.

Hawaii State Department of Health (DOH) monitors monthly for enterococci and C. perfringins using the membrane filtration method at two Honokohau Harbor boat ramps directly adjacent to the park and two locations near the pier in Kailua Bay, a few miles to the South. Portable meters are used at these collection sites to measure temperature, salinity, turbidity, dissolved oxygen, and percent dissolved oxygen.

J. PUHO

No water quality monitoring is being done in this park at this time.

K. HAVO

David Foote (USGS) has a funded I&M project to survey selected invertebrates and water chemistry in some anchialine pools.

The USGS has stream gauges and monitoring wells outside of park boundaries, but within the watershed. The parameters monitored in streams are temperature, flow, depth, turbidity, color, specific conductance, dissolved solids, dissolved oxygen, pH, carbon dioxide, alkalinity, bicarbonate, carbonate, nitrite/nitrate, ortho-phosphate, phosphorous, silicon, total hardness, dissolved minerals; calcium, magnesium, sodium, potassium, chloride, sulfate, and fluoride, and the metals; hexavalent chromium, cobalt, copper, iron, lead, manganese, nickel, strontium, zinc, aluminum, and lithium. Assays were performed to determine total coliform using membrane filtration.

Desired Future Conditions

After collaboration with government and academic experts on marine and freshwater conditions throughout the pacific network of national parks, the following priorities for the future have come to the fore. The primary goal is the protection of ecological health, condition, and function so that the water quality is of a level to support biodiversity, larval dispersal, growth and reproduction. This goal is to be accomplished while accommodating cultural uses which influence water quality. These two priorities necessitate the third which is to disseminate water quality information widely, and with interpretation, so that park managers, government regulating agencies, and commercial and recreational users can understand the shared values of the resource in question and manage it appropriately. It is everyone's desire to fulfill these goals, but when resources are not valued in the same way by all, the way to achieve them is not so clear.

To be successful in the stewardship of water resources, we should keep conditions at least at the present level of quality, with no further degradation, and initiate recovery or restoration of degraded areas. This means maintaining natural processes or patterns with sustainable resources varying within normal ranges for the given climate. Naturally existing shoreline conditions and dynamics should be maintained. An environment conducive to the survival and perpetuation of native biological communities will encourage a diverse ecosystem with healthy populations. This is especially critical to the protection of rare or endangered biota. One important aspect of this is the identification and preservation of the water quality in nursery areas. Turbidity and nutrient levels are important indicators of change and should be maintained in the natural condition.

Human influence is often contrary to achieving the goals stated above. It is highly desirable that land use does not affect sediment or nutrient dynamics in aqueous systems. The impact of cultural uses, past and present, should be defined so that management practices can be developed where human disturbances are minimized. In addition, standards for all states and territories in the network need to be reviewed with the sustainability of the resource as the goal. This may require different standards for different water bodies and habitat types as well as different baseline criteria to be monitored.

Understanding human impact on water quality is achievable through the planned monitoring program, but for the most part we do not have baselines to work from in the pacific network. It is important to recognize that our conception of what is attainable may change over time and so preliminary monitoring will be necessary to come up with more specific desired future conditions. Currently unimpaired waters should be used as a baseline for ideal conditions, and these areas should be island-specific. This is also helpful with sliding baselines (define).

A successful monitoring program will relate to management questions which are consistent with the mission of NPS, its resource protection goals, and the enabling legislation for individual parks. And conversely, successful management of park water resources will rely heavily on the monitoring questions asked.

Water Quality Monitoring Boundaries

A. Park Lands

Water resources in the Pacific Island Network (or PACN) are governed by layers of legislation concerning park boundaries, state boundaries, and private or territorial lands and waters. Consequently, park water resources are affected by activities and conditions in areas out of their jurisdiction. Streams which pass through a park may be altered upstream through diversion or use as an outfall for industrial waste. Offshore currents may bring pollutants from nearby industrialized areas into an embayment or onto a reef. Fire and flood may increase sediment loading through a surrounding watershed. This leads to the conclusion that monitoring the water quality of areas outside of the parks is imperative to the successful management of all resources inside the parks.

Watersheds: Watersheds will be included due to the simple fact that water flows down hill, and streams originating inside or upslope of parks are affected by both natural and anthropogenic events. Most PACN parks are located in areas with high precipitation and porous substrate contributing to pollutants leaching directly into coastal areas. Those with more arid or less porous conditions are vulnerable to catastrophic flood events which result in erosion and uncontrolled dispersion of urban wastes.

Nearshore: Many of the PACN parks are located next to population centers with poor or non-existent waste treatment facilities and various sources of industrial pollutants. Currents running parallel to the shoreline can carry pollutants from nearby human activities into parks or cause changes in beach areas managed by the park.

B. Marine Boundaries

For offshore distances, arbitrary distances of ½ mile, or depth contours of 100’ or 120’ are being considered. In all cases, the existing park boundary should be used if it extends farther than the chosen criteria. Offshore study areas should extend laterally along the coast from the authorized park boundary up to one half mile up current or to the next point which may create an embayment. In most shoreline parks, the current runs from east to west. They should also encompass any immediately adjacent embayment, up or down current

C. Land Boundaries

Stream water and groundwater quality can be helpful for determining early warning signs of change. Water quality study areas should encompass the entire park land area and be inclusive of the adjacent watershed. They should extend from the park boundary upslope to the top of the watershed, and downslope approximately 1 mile. In some Western Pacific Islands, the whole island may be included as the monitoring area using this criteria. On the island of Hawaii, this may mean watersheds that are orders of magnitude larger than parks. After preparing draft samples of maps reflecting these boundaries for all parks, these definitions will be refined.

D. Revision Process

Using the strategy outlined above, proposed areas of interest for monitoring were drawn onto existing park maps. Some parks make up their own watershed and are quite expansive, while others are dwarfed by their surrounding watershed. In either case, the proposed area could cover most of the island. For this reason two types of maps were made. The marine boundary map shows the proposed shoreline boundary up and down current from the park borders along with both proposed offshore limits. Lines showing where 1/2 mile from the shoreline and the 120 foot depth contour are also shown. Another map depicts each park within its respective watershed. Proposed maps for each park can be found in Appendix G. The locations of USGS monitoring wells and stream gauges will be included in future monitoring area maps. These preliminary charts will be circulated back to the resource staff at each park and other qualified experts for comment. Final monitoring areas will be proposed after a thorough review and consultation process which includes the practicality of the scope of work involved.

CONCEPTUAL MODEL

Determination of water quality is an integral part of understanding the condition of natural resources but its relevance to their management is a matter of perspective. Conceptual models of ecosystem components and their relationships are an effective way of communicating this perspective and relating the objectives of monitoring to the management issues at hand. They can also aid planners in prioritization of monitoring needs and as justification in selecting vital signs.

After consultation with resource managers at PACN parks, the PACN Water Quality Workgroup developed a first draft conceptual model for use in relating water quality to ecosystems in the Pacific Islands. At this stage, the model is meant to encompass water quality for all resource types (fresh, marine, and ground water). This model is intended to help distinguish causal relationships between natural resources, human activity, nature, and water quality. The revision process encourages discussion about ecosystem issues and assists managers and monitoring planners in communicating complex ideas about ecological processes.

The model shown in Figure 1 and described here is the most current version which has incorporated comments from members of the water quality workgroup and WRD staff. Primarily, the connections between drivers and stressors were made clearer while keeping the model broad enough for this stage of the process.

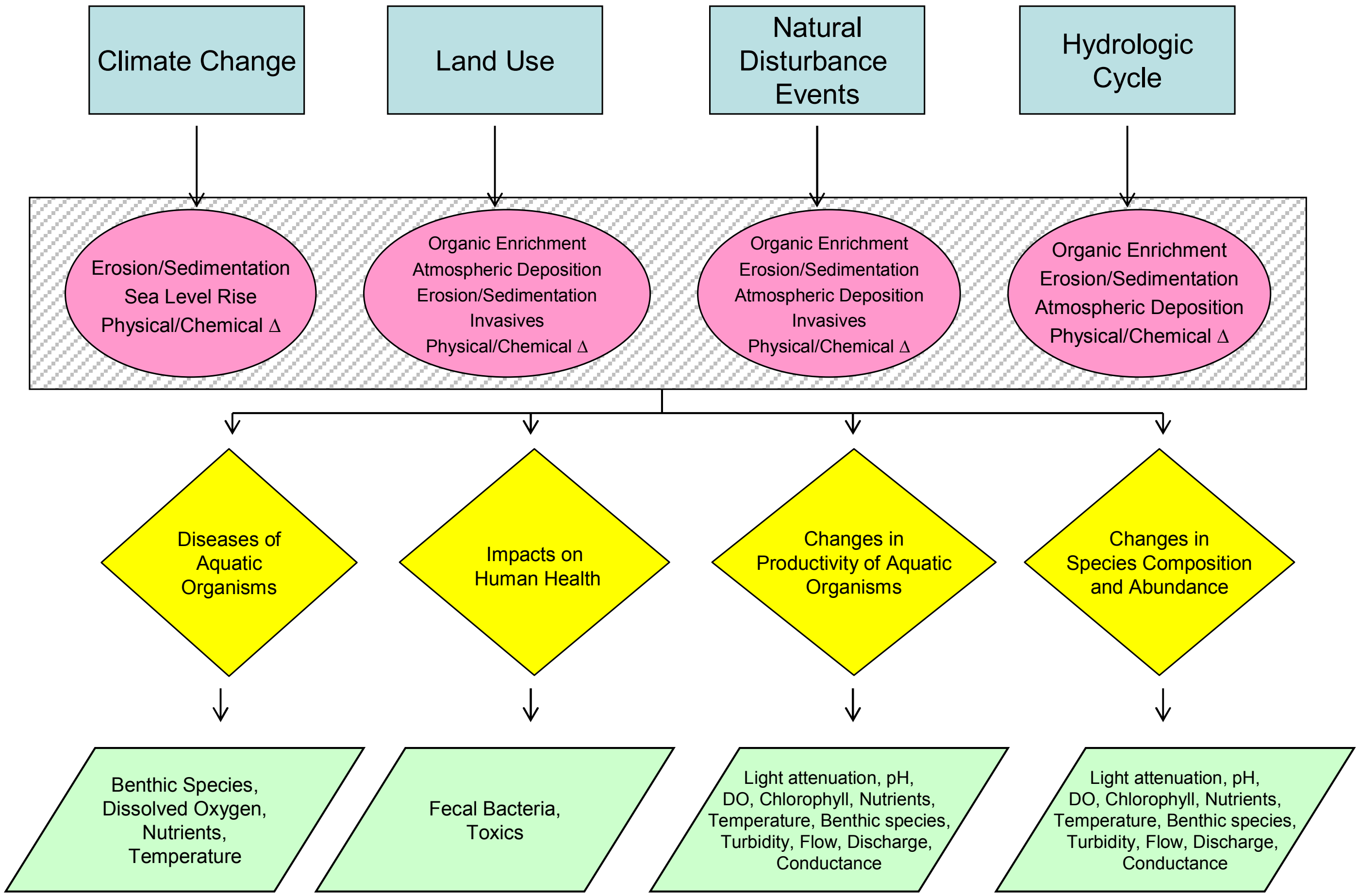

Figure 1. Water Quality Conceptual Model

A. Drivers and Stressors

Drivers and stressors are factors that directly influence the environment and may have human or natural origins. Drivers are situations in which stressors are generated. Stressors are changes in natural conditions that result from the operation of a driver. Drivers occur independently of one another, but may also operate simultaneously, magnifying the effect of associated stressors on the ecosystem. This is indicated in the conceptual model by enclosure of the stressors into one box relating to ecosystem responses. In the interest of including all water types, this model represents a very broad explanation of aquatic systems.

1. Climate Change

Change in climate refers to global processes that affect ambient conditions in such a way that prospective conditions are different from historical ones. In the PACN, coastal parks are impacted by the rising sea level as global warming alters the physical condition of seawater. Changes in sea level affect shoreline dynamics and hydrological factors leading to erosion of coastal areas and sedimentation of nearshore areas. Coastal wetlands, anchialine pools, and historical fishponds are most threatened by changes in this condition. The impact to areas concerned about seawater intrusion into drinking water sources is also important. Nearshore habitats may experience regime shifts when temperatures are no longer tolerable to corals leading to changes in benthic habitat, species composition, and offshore topography. Terrestrial ecosystems may experience similar changes in composition and structure due to climatic influences.

2. Human Use

The occurrence of human activity inevitably results in stress to environmental resources. Organic enrichment and other chemical changes in water quality may occur due to the presence of farms, sewers, solid waste, and landscaped areas. The construction of roads, piers, and barriers in coastal areas, as well as stream channelization, contributes to erosion and subsequent sedimentation, in addition to other physical and chemical changes in aquatic environments. Power plants, vehicles and construction activities are sources of particulates that cause contamination of water resources through atmospheric deposition, discharges, and storm events. Human population growth and resulting urban development destroys native habitat simultaneously introducing new species into disturbed areas where they out-compete the native biota. Removal of vegetation can influence precipitation patterns increasing the likelihood that drought, fire, and erosion will contribute to degradation of streams, wetlands, anchialine pools, fishponds, and reefs. Recreational and commercial activities involving fishing, swimming, and boating impact marine and stream resources by influencing species composition and the introduction of chemical and physical pollutants.

3. Natural Disturbance Events

Flooding, and high winds, such as occur during hurricanes, or typhoons, can drastically change water quality by disturbing structures designed to contain pollutants. Sewers and storm drains may overflow into streams causing physical and chemical changes that eventually affect groundwater and/or nearshore receiving waters. Erosion and sedimentation is accelerated directly and through destruction of vegetation. Disturbed habitats are likely to be repopulated with invasive species. Atmospheric deposition, earthquakes, and tsunamis are examples of natural events that can influence water resources unpredictably.

4. Hydrologic Cycle

Understanding water flow and its rate of movement is an important aspect of water quality monitoring. Different water resources may impact one another through direct connections such as a stream entering the ocean, or indirectly as in evaporation from the ocean falling on terrestrial water bodies as rain. Flowing water carries its physical and chemical qualities to the receiving body and, depending on the flow rate, may bring parts of the substrate as well. When a system is operating within natural ranges of flow, potential stressors are balanced over time by ecosystem processes. Changes in the hydrologic cycle may offset the capacity of a system to restore itself, resulting in degraded water quality. For example, groundwater reservoirs are recharged by rainfall in undisturbed systems. When groundwater is withdrawn at a higher rate than it is replenished, changes in relative quantity are accompanied by physical and chemical changes that will affect other water bodies dependant on this groundwater supply.

B. Ecosystem Responses and Measures of Change

In order to evaluate water resource issues, an understanding of the effects of stressors on the ecosystem is important. PACN ecosystem responses were divided into generalized categories represented by diamonds in the model and described below. Once the issues of ecosystem changes are described and prioritized, metrics can be applied to test the theorized relationships.

1. Diseases of Aquatic Organisms

Examples of diseases in aquatic organisms are coral bleaching due to elevated temperatures, coral and macroalgae smothering caused by sedimentation, and “red tide” algal blooms brought about by organic enrichment. Bioaccumulation of toxins and metals increases the incidence of tumors and other diseases. Economic effects are likely when fisheries or tourist areas are degraded in these ways.

Many measures of change are obvious as in measuring temperature to monitor coral bleaching due to global warming or nutrients as a factor in algal blooms. Areas with little or no flow that support animals are susceptible to die-offs due to insufficient oxygen levels. The long-term stress of less than ideal conditions contributes to variation in growth, survival, and reproduction rates among species which can be quantified by monitoring benthic organisms.

2. Impact on Human Health

When marine ecosystems become contaminated, there is a great impact to island communities reliant on subsistence fishing and tourism. Unfortunately, toxins and microbial contamination are already affecting fishing areas and recreational opportunities throughout the PACN. For populations dependent on surface or groundwater supplies for drinking water and irrigation, maintaining the quality of these resources is imperative to sustaining their quality of life.

Although the stressors that affect human health are many, the measurable effects are limited to fecal bacteria and chemical contaminants such as mercury or PCBs. The majority of aquatic monitoring programs in place now are directed at human health parameters.

3. Change in Primary Productivity

When species are influenced by environmental stressors, they often experience changes in growth, survival and reproduction. Changes in productivity affect ecosystem processes such as nutrient cycling and the rate of succession, compounding the effect of the stressors themselves.

There are many measures and even more methods for describing productivity. Benthic species abundance and composition is often used to characterize an ecosystem in terms of general water quality parameters. Certain species need specific conditions of water clarity, nutrient availability, temperature, pH, primary productivity, dissolved oxygen, and salinity. Some chosen parameters may not directly affect productivity, but are likely a factor in the impact of another, related variable in the ecosystem process. For example, the rate of water flow into and out of a system is crucial to tracking the dynamics of nutrient cycling, temperature, salinity, and the accompanying changes in indicators of primary productivity; chlorophyll a, pH, dissolved oxygen, and clarity.

4. Change in Biological Species and Abundance

Just as with productivity, the composition of species and their relative abundance is a factor of reproduction, growth, and survival as determined by the influence of environmental stressors.

The close relationship of change in productivity to change in species composition and abundance is reflected by the same array of parameters to describe them. As with change in productivity, some measures are direct indicators of change and some help assess the expected impact of other stressors. For example, benthic surveys are direct indicators of species and abundance, while flow or discharge rates control the influx of nutrients and other measured parameters indirectly affect these attributes.

C. Review and Revision

Just as natural systems are dynamic, the conceptual model must be also. As more is learned about the interactions of its components, the model should be modified to reflect all aspects found to be significant to water resources. The importance of issues or weight of effects are not demonstrated in this diagram but maybe added later or used in more detailed models of specific water types.

Through the circulation, discussion, and subsequent remodeling of this diagram, NPS staff and other concerned parties will learn more about aquatic ecosystems as well as the concerns of other stakeholders for them. Development of this model will help to promote expansion of resource conservation from the traditional values of human health concerns to include resource sustainability. As this model develops, so does the prioritization of issues in the PACN which require water quality monitoring. It is intended that these processes work together so that the monitoring program reflects the needs and priorities of the PACN parks.

Appendix A: Workgroup Membership

• Sallie Beaver	Kaloko-Honokohau National Historic Park
• Gary Denton	Water and Environmental Research Institute (Guam)
• Guy DiDonato	American Samoa Environmental Protection Agency
• Roy Irwin	National Park Service – Water Resource Division
• Ed Laws	University of Hawai'i at Manoa
• June H. Lum	Department of Health, State of Hawai'i
• Kevin Summers	US Environmental Protection Agency, Gulf Ecology Division
• Bill Walsh	Department of Aquatic Resources, State of Hawai'i
• Wendy Wiltse	Environmental Protection Agency, Hawai'i Division

Appendix B: Sources Reviewed: Contributors to Water Quality Meeting

A. FEDERAL GOVERNMENT

National Park Service

- Eva DiDonato – Marine Ecologist, National Park of American Samoa (NPSA), Water Quality Workgroup Lead, Pacific Island Network (PACN).
- Darcy Hu – PACN Science Advisor
- Fritz Klasner – PACN Ecologist
- Gordon Dicus – PACN Database Manager
- Roy Irwin – Biologist, Water Resources Division
- Peter Craig – Ecologist, National Park of American Samoa
- Sallie Beavers – Ecologist, Kaloko Honokohau National Historic Park
- Dwayne Minton – Ecologist, War in the Pacific National Historic Park
- Larry Basch – Marine Ecologist, Pacific Islands Coral Reef Program Senior Science Advisor
- Stan Bond – Biologist, Kaloko Honokohau National Historic Park
- Ana Dittmar – Chief of Cultural and Natural Resources, Puuhonua O Honaunau National Historic Park
- Eric Andersen – Park Ranger, Kipahulu Unit Manager, Haleakala National Park
- Sandy Margriter – GIS Specialist, Hawaii Volcanoes National Park

United States Environmental Protection Agency

- Kevin Summers – Associate Director of Science, Gulf Ecology Division

United States Geological Survey

- Gordon Tribble – District Chief, Hawaii Water Resources

D. STATE GOVERNMENT

- Bill Walsh – Aquatic Biologist, Department of Land and Natural Resources, Hawaii Office

- Bob Nishimoto – Aquatic Biologist, Department of Land and Natural Resources, Hawaii Office

E. ACADEMIA

- Ed Laws – University of Hawaii at Manoa, Department of Oceanography
- Joan Yoshioka – Program Facilitator, Pacific Island Network Inventory and Monitoring Program
- Kimber Deverse – Water Quality Workgroup Facilitator, RCUH Contractor
- Allison Cocke – Ecological Monitoring Spatial Data Specialist, RCUH Contractor

F. NON-GOVERNMENT ORGANIZATIONS

- Sara Peck – University of Hawaii Sea Grant Extension Agent, West Hawaii

Appendix C: Sources Reviewed (Data Mining): Potential partners

- EPA (Guam, American Samoa, Hawaii)
- NPS
- NPS-WRD (Baseline Water Quality Data Inventory and Analysis for the Hawaiian Parks)
- USGS-WRD
- State of Hawaii (Department of Land and Natural Resources, Department of Aquatic resources, Seagrant-both state and NOAA, DOH)
- Universities (Hawaii at Manoa and Hilo, Guam, California at Santa Cruz, American Samoa Community College, North Carolina)
- Bureau of Coastal Zone Management (Guam)
- NOAA-NMS
- USFWS
- Molokai Community Watershed Coalition
- Bishop Museum
- NRCS
- NGOs – e.g. The Nature Conservancy
- UG-WERI
- American Samoa DMWR
- USDA-NRCS (MKSWCD)
- US NAVY

Appendix D: PACN water quality designations

Table 1. Water quality designations in PACN parks.

Park	Unique or Pristine Resources[a]	303d[b]	Groundwater[c]	Inland Waters designation[d]	Marine Waters Designation[e]	Marine Bottom Ecosystem designation[f]
WAPA	Wetlands	Agana Bay and the Northern Guam Lens Aquifer (NGL)	NGL perimeter is G2[g]	S3	Asan and Agat are designated M2.	NA
AMME	Wetlands	Saipan Lagoon	Management zones are currently under development[h]	Class 1[i]	Class A[j]	NA [j]
NPSA[k]	Coastal waters off Ofu and Ta`u, and Laufuti Stream	None	1G and 2G	Class 1 and Class 2	Embayment and Open Coastal	NA
USAR	None	Pearl Harbor	NA	NA	A	II
KALA	Kahakau crater lake and coastal waters	None	NA[c]	1a	AA	I
HALE	Streams, springs, and coastal waters in Kipahulu district and sub-alpine lakes	None	NA[c]	1a (possibly 1b also)	AA[j]	I[j]
ALKA	Park traverses coastal waters, wetlands, streams, and anchialine pool complexes	Pelekane Bay, Spencer Park Beach, Hapuna Beach, Kailua Bay, Magic Sands Beach, and Kealakekua Bay	NA[c]	1a	A and AA[j]	I and II[j]
PUHE	None	Pelekane Bay	NA[c]	1a	AA	II
KAHO	Wetlands, anchialine pools, and coastal waters	None	NA[c]	1a	A and AA	I and II
PUHO	anchialine pools and coastal waters	None	NA[c]	1a	AA[j]	II[j]
HAVO	anchialine pools, coastal waters, and Ola`a bogs	None	NA[c]	1a	AA[j]	II[j]

Park Unique or Pristine Resourcesa 303db Groundwaterc Inland Waters designationd Marine Waters Designatione Marine Bottom Ecosystem designationf

Park	Unique or Pristine Resources[a]	303d[b]	Groundwater[c]	Inland Waters designation[d]	Marine Waters Designation[e]	Marine Bottom Ecosystem designation[f]
WAPA	Wetlands	Agana Bay and the Northern Guam Lens Aquifer (NGL)	NGL perimeter is G2[g]	S3	Asan and Agat are designated M2.	NA
AMME	Wetlands	Saipan Lagoon	Management zones are currently under development[h]	Class 1[i]	Class A[j]	NA [j]
NPSA[k]	Coastal waters off Ofu and Ta`u, and Laufuti Stream	None	1G and 2G	Class 1 and Class 2	Embayment and Open Coastal	NA
USAR	None	Pearl Harbor	NA	NA	A	II
KALA	Kahakau crater lake and coastal waters	None	NA[c]	1a	AA	I
HALE	Streams, springs, and coastal waters in Kipahulu district and sub-alpine lakes	None	NA[c]	1a (possibly 1b also)	AA[j]	I[j]
ALKA	Park traverses coastal waters, wetlands, streams, and anchialine pool complexes	Pelekane Bay, Spencer Park Beach, Hapuna Beach, Kailua Bay, Magic Sands Beach, and Kealakekua Bay	NA[c]	1a	A and AA[j]	I and II[j]
PUHE	None	Pelekane Bay	NA[c]	1a	AA	II
KAHO	Wetlands, anchialine pools, and coastal waters	None	NA[c]	1a	A and AA	I and II
PUHO	anchialine pools and coastal waters	None	NA[c]	1a	AA[j]	II[j]
HAVO	anchialine pools, coastal waters, and Ola`a bogs	None	NA[c]	1a	AA[j]	II[j]

NA. Not applicable to this park.

a. Outstanding Natural Water Resources have not been designated in the PACN region.

b. Refers to a section of the Clean Water Act that requires states to identify and list impaired water bodies (see http://www4.law.cornell.edu/uscode/33/1313.html for full details).

c. Groundwater designations have not been developed by the State of Hawaii. For identification and description of Hawaiian Island aquifers see "Aquifer Identification and Classification of Hawaiian Islands: Groundwater Protection Strategy for Hawaii," 6 reports (1990-1993) by John F. Mink and L. Stephen Lau. for the University of Hawaii Water Resources Research Center.

d. See http://www.hawaii.gov/doh/rules/11-54.pdf for full details.

e. See http://www.hawaii.gov/doh/rules/11-54.pdf for full details.

f. see http://www.hawaii.gov/doh/rules/11-54.pdf for full details.

g. From the Unified Watershed Assessment 1998 Clean Water Action Plan for Guam available at http://www.guamepa.govguam.net/programs/water/GuamCWAP.pdf

h. See http://www.epa.gov/ost/standards/wqslibrary/territories/northern_mariana_9_wqs.pdf for full details.

i. See http://www.epa.gov/ost/standards/wqslibrary/territories/northern_mariana_9_wqs.pdf for full details.

j. Authorized park boundary only borders, does not encompass, marine waters.
k. See http://www.epa.gov/ost/standards/wqslibrary/territories/american_samoa_9_wqs.pdf for full details.

Appendix E: Surface Water Bodies in the PACN

Table 2: Partial list of non-marine aquatic resources associated with PACN parks. Resources may not be within authorized park boundaries, but are within desired water quality monitoring boundaries. List includes most of the named waterbodies, but not many smaller resources like seeps and springs.

Park	Name	Type	Location	Other
WAPA	Maina	Spring	possibly: Fonte Plateau Unit	
	Asan	River	mouth & part of body	
	Asan	Spring	possibly: Asan Unit	
	Matgue	River	mouth & part of body	
	Taguag	River	part of body, Piti Unit	
	Masso	River	possibly: part of body, Piti Unit	
	Namo	River	mouth, Agat Unit	
	Togcha	River	mouth & headwaters, Agat/Mt. Alifan Unit	
	Salinas	River	mouth & headwaters, Agat/Mt. Alifan Unit	
	Finile	Creek	mouth & possibly headwaters, Agat/Mt. Alifan Unit	
	Finile	Spring	possibly: 2 of 3 springs, Mt. Alifan Unit	
	Gaan	River	mouth, possibly headwaters, Agat/Mt. Alifan Unit	
	Auau	Stream	mouth, Agat Unit	
	Ylig	River	possibly: headwaters, Mt. Chachao/Mt. Tenjo Unit	
	(several)	Wetland	upland areas	
	(several)	Wetland	coastal areas	
AMME	(unnamed?)	Stream	on border	in Garapan
	"AMME"	Wetland	within park	
NPSA	Agaputuputu	Stream	mouth, Ofu	
	Tafe	Stream	mouth, Ofu	
	Ulafala	Stream	mouth, Ofu	
	Vainuulua	Stream	mouth, Ofu	
	Alei	Stream	Olesega	
	Vaaui	Stream	Olesega	
	Sinapoto	Stream	Olesega	
	Talaisina	Stream	Olesega	
	Topea	Stream	Olesega	
	Etemuli	Stream	Olesega	
	Papausi	Stream	Olesega	
	(unknown)	Stream	upland stream, Tutuila	possibly intermittent
	(unknown)	Stream	possibly: on border, Ta`u	possibly intermittent
	Laufuti	Stream	whole stream, Ta`u	
	Leua	Stream	possibly on border, headwaters, Tutuila	
	(unknown)	Stream	several, Tutuila	possibly intermittent
	Nu`utogo	Stream	Tutuila	
	Vaisa	Stream	Tutuila	
	Gaoa	Stream	Tutuila	

Park	Name	Type	Location	Other
	Lausaa	Stream	Tutuila	
	Faatafe	Stream	Tutuila	
	Mulivai	Stream	Tutuila	
	Vaiola	Stream	Tutuila	
	Tiaiu (Falls)	Stream	at least headwaters, Tutuila	
USAR	Halawa	Stream	not within park	
	Kalauao	Stream	not within park	
	Waimalu	Stream	not within park	
	Waiawa	Stream	not within park	
	others?	Stream	not within park	possibly intermittent
KALA	Waikolu	Stream	not headwaters	
	Wailea	Stream	not headwaters	
	Waihanau	Stream	not headwaters	intermittent
	Pelekunu	Stream	possibly headwaters	
	Kauhako	Lake	within park	
HALE	Waiho`i	Bog	below park boundary, upper Hana	
	State	Bog	below park boundary, upper Hana	
HALE	Big	Bog	upper Hana	
	Mid-Camp	Bog	upper Hana	
	Greensword	Bog	upper Hana	
	New	Bog	upper Hana	
	Flat Top	Bog	upper Hana	
	Wai`ele`ele	Lake	upper Hana	
	Wai`anapanapa	Lake	upper Hana	
	"Wai Nene"	Lake	upper Hana	not perennial
	Kalepa	Stream	Ka`apahu tract	forms west boundary
	`Alelele	Stream	Ka`apahu tract	
	Leleka	Stream	Ka`apahu tract	
	(unnamed)	Stream	Ka`apahu tract	intermittent (lower reaches)
	Kukuiula	Stream	Ka`apahu tract, upstream section	forms east boundary?
	Pipiwai	Stream	Kipahulu tract (`Oheo)	Pipiwai/Palikea join in `Oheo Gulch
	Palikea	Stream	Kipahulu tract (`Oheo)	Pipiwai/Palikea join in `Oheo Gulch
	Pua`alu`u	Stream	Kipahulu tract	
	Kalena	Stream	Kipahulu tract, only upper portion	
	Kalena	Stream	Kipahulu tract, only upper portion	
	(seasonal)	Stream	Kaupo Gap ?	
ALKA	?	?[1]	resources have yet to be identified	
PUHE	Makahuna?	Stream	mouth & part of body	upper reaches intermittent
KAHO	Kaloko	Fishpond	within park	
	Kaloko	wetland	within park	
	`Aimakapa	Fishpond	within park	
	Anchialine	Ponds	several	
	`Aimakapa	Wetland	yes: associated w. `Aimakapa Pond	
PUHO	"Royal"	Fishpond	within park	
	(no name)	Wetland	within park	
	Anchialine	Ponds	several	4 ponds + 2 waterholes
	Ki`ilae	Stream	mouth	intermittent
HAVO	(ephemeral)	Streams	Ka`u region	intermittent
	(several)	Ponds	several anchialine ponds	
Park	Name	Type	Location	Other
WAPA	Maina	Spring	possibly: Fonte Plateau Unit	

[1] Multiple aquatic resources exist along the trail route, including coastal wetlands, anchialine ponds, inland Hawaiian fishponds, and streams.

Park	Name	Type	Location	Other
	Asan	River	mouth & part of body	
	Asan	Spring	possibly: Asan Unit	
	Matgue	River	mouth & part of body	
	Taguag	River	part of body, Piti Unit	
	Masso	River	possibly: part of body, Piti Unit	
	Namo	River	mouth, Agat Unit	
	Togcha	River	mouth & headwaters, Agat/Mt. Alifan Unit	
	Salinas	River	mouth & headwaters, Agat/Mt. Alifan Unit	
	Finile	Creek	mouth & possibly headwaters, Agat/Mt. Alifan Unit	
	Finile	Spring	possibly: 2 of 3 springs, Mt. Alifan Unit	
	Gaan	River	mouth, possibly headwaters, Agat/Mt. Alifan Unit	
	Auau	Stream	mouth, Agat Unit	
	Ylig	River	possibly: headwaters, Mt. Chachao/Mt. Tenjo Unit	
	(several)	Wetland	upland areas	
	(several)	Wetland	coastal areas	
AMME	(unnamed?)	Stream	on border	in Garapan
	"AMME"	Wetland	within park	
NPSA	Agaputuputu	Stream	mouth, Ofu	
	Tafe	Stream	mouth, Ofu	
	Ulafala	Stream	mouth, Ofu	
	Vainuulua	Stream	mouth, Ofu	
	Alei	Stream	Olesega	
	Vaaui	Stream	Olesega	
	Sinapoto	Stream	Olesega	
	Talaisina	Stream	Olesega	
	Topea	Stream	Olesega	
	Etemuli	Stream	Olesega	
	Papausi	Stream	Olesega	
	(unknown)	Stream	upland stream, Tutuila	possibly intermittent
	(unknown)	Stream	possibly: on border, Ta`u	possibly intermittent
	Laufuti	Stream	whole stream, Ta`u	
	Leua	Stream	possibly on border, headwaters, Tutuila	
	(unknown)	Stream	several, Tutuila	possibly intermittent
	Nu`utogo	Stream	Tutuila	
	Vaisa	Stream	Tutuila	
	Gaoa	Stream	Tutuila	
	Lausaa	Stream	Tutuila	
	Faatafe	Stream	Tutuila	
	Mulivai	Stream	Tutuila	
	Vaiola	Stream	Tutuila	
	Tiaiu (Falls)	Stream	at least headwaters, Tutuila	
USAR	Halawa	Stream	not within park	
	Kalauao	Stream	not within park	
	Waimalu	Stream	not within park	
	Waiawa	Stream	not within park	
	others?	Stream	not within park	possibly intermittent
KALA	Waikolu	Stream	not headwaters	
	Wailea	Stream	not headwaters	

Park	Name	Type	Location	Other
	Waihanau	Stream	not headwaters	intermittent
	Pelekunu	Stream	possibly headwaters	
	Kauhako	Lake	within park	
HALE	Waiho`i	Bog	below park boundary, upper Hana	
	State	Bog	below park boundary, upper Hana	
HALE	Big	Bog	upper Hana	
	Mid-Camp	Bog	upper Hana	
	Greensword	Bog	upper Hana	
	New	Bog	upper Hana	
	Flat Top	Bog	upper Hana	
	Wai`ele`ele	Lake	upper Hana	
	Wai`anapanapa	Lake	upper Hana	
	"Wai Nene"	Lake	upper Hana	not perennial
	Kalepa	Stream	Ka`apahu tract	forms west boundary
	`Alelele	Stream	Ka`apahu tract	
	Leleka	Stream	Ka`apahu tract	
	(unnamed)	Stream	Ka`apahu tract	intermittent (lower reaches)
	Kukuiula	Stream	Ka`apahu tract, upstream section	forms east boundary?
	Pipiwai	Stream	Kipahulu tract (`Oheo)	Pipiwai/Palikea join in `Oheo Gulch
	Palikea	Stream	Kipahulu tract (`Oheo)	Pipiwai/Palikea join in `Oheo Gulch
	Pua`alu`u	Stream	Kipahulu tract	
	Kalena	Stream	Kipahulu tract, only upper portion	
	Kalena	Stream	Kipahulu tract, only upper portion	
	(seasonal)	Stream	Kaupo Gap ?	
ALKA	?	? 2	resources have yet to be identified	
PUHE	Makahuna?	Stream	mouth & part of body	upper reaches intermittent
KAHO	Kaloko	Fishpond	within park	
	Kaloko	wetland	within park	
	`Aimakapa	Fishpond	within park	
	Anchialine	Ponds	several	
	`Aimakapa	Wetland	yes: associated w. `Aimakapa Pond	
PUHO	"Royal"	Fishpond	within park	
	(no name)	Wetland	within park	
	Anchialine	Ponds	several	4 ponds + 2 waterholes
	Ki`ilae	Stream	mouth	intermittent
HAVO	(ephemeral)	Streams	Ka`u region	intermittent
	(several)	Ponds	several anchialine ponds	

1 Multiple aquatic resources exist along the trail route, including coastal wetlands, anchialine ponds, inland Hawaiian fishponds, and streams.

Appendix F: PACN Monitoring and Issues

Table 3. This table indicates the status of current water quality monitoring for each parks resources and their associated stressors. "Long term" programs are marked with a C if they are comprehensive and complement our resource monitoring goals for the park, while an X indicates that it is limited in scope or sampling location. "Short term" projects have a set completion date and generally focus on a specific resource or issue. Some projects are considered "suspended" due to lack of funding although they may have been collecting important data for some time. "In prep" describes studies that are pending or being implemented at this time. Most resource stressors are "unaddressed" in regards to water quality monitoring as shown below.

Table 3. Water quality monitoring for park resources & associated stressors

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
WAPA	Streams	Climate Change				X	
		Erosion				X	
		Hydrology		X			
		Invasives					X
		Microbial Contamination				X	
		Organic Enrichment		X		X	
		Sedimentation		X			
		Toxics		X		X	
	Groundwater	Hydrology		X	X		
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics		X			
	Wetlands	Atmosheric Deposition					X
		Climate Change		X			
		Erosion		X			
		Hydrology		X			
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment		X			
		Sedimentation		X			
		Toxics		X			
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants	X				
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change		X	X		
		Hydrology		X			
		Invasives			X		
		Microbial Contaminants					X
		Organic Enrichment			X		
		Sedimentation	C		X		
		Toxics		X	X		

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
WAPA	Streams	Climate Change				X	
		Erosion				X	
		Hydrology		X			
		Invasives					X
		Microbial Contamination				X	
		Organic Enrichment		X		X	
		Sedimentation		X			
		Toxics		X		X	
	Groundwater	Hydrology		X	X		
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics		X			
	Wetlands	Atmosheric Deposition					X
		Climate Change		X			
		Erosion		X			
		Hydrology		X			
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment		X			
		Sedimentation		X			
		Toxics		X			
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants	X				
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change		X	X		
		Hydrology		X			
		Invasives			X		
		Microbial Contaminants					X
		Organic Enrichment			X		
		Sedimentation	C		X		
		Toxics		X	X		

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE

			long-term	short-term	in-prep	suspended	unaddressed
AMME	Streams	Climate Change					X
		Erosion		X			
		Hydrology		X	X		
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment		X			
		Sedimentation					X
		Toxics		X			
	Groundwater	Hydrology		X	X		
		Microbial Contaminants					X
		Organic Enrichment		X			
		Toxics		X			
	Wetlands	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology		X	X		
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics		X			
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants	C				
		Organic Enrichment	C				
		Toxics					X
	Nearshore/coastal	Climate Change	C				
		Hydrology					X
		Invasives					X
		Microbial Contaminants	C				
		Organic Enrichment	C				
		Sedimentation	C				
		Toxics			X		

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
NPSA	Streams	Climate Change		X			
		Erosion					X
		Hydrology		X	X		
		Invasives					X
		Microbial Contaminants		X	X		
		Organic Enrichment		X	X		
		Sedimentation					X
		Toxics			X		
	Groundwater	Hydrology				X	
		Micobial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change	X	X			
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment		X			
		Sedimentation					X
		Toxics					X
	Tide Pools	Climate Change					X
		Micobial Contaminants					X
		Organic Enrichment					X

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
USAR	Streams	Climate Change					X
		Erosion					X
		Hydrology				X	
		Invasives					X
		Microbial Contaminants				X	
		Organic Enrichment				X	
		Sedimentation					X
		Toxics				X	
	Groundwater	Hydrology				X	
		Micobial Contaminants				X	
		Organic Enrichment				X	
		Toxics				X	
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change					X
		Hydrology		X			
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment	C	X			
		Sedimentation		X			
		Sedimentation	C				
		Toxics	C	X			

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
KALA	Streams	Climate Change					X
		Erosion					X
		Hydrology				X	
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Groundwater	Hydrology				X	
		Microbial Contaminants				X	
		Organic Enrichment				X	
		Toxics				X	
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Kahakau Crater	Organic Enrichment					X
		Toxics					X
		Hydrology					X

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
HALE	Sub-alpine Lakes	Atmospheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Streams	Climate Change					X
		Erosion					X
		Hydrology				X	
		Invasives					X
		Microbial Contaminants				X	
		Organic Enrichment				X	
		Sedimentation					X
		Toxics					X
	Groundwater	Hydrology				X	
		Micobial Contaminants				X	
		Organic Enrichment				X	
		Toxics				X	
	Anchialine Pools	Atmosheric Deposition					X
		Climate Change					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Coastal Springs	Hydrology					X
		Organic Enrichment				X	
		Toxics					X
		Microbial Contaminants				X	

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
ALKA	Streams	Climate Change					X
		Erosion	X				
		Hydrology	X			X	
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation	X				
		Toxics					X
	Groundwater	Hydrology			X	X	
		Microbial Contamination	X			X	
		Organic Enrichment	X		X	X	
		Toxics				X	
	Anchialine Pools	Atmosheric Deposition					X
		Climate Change					X
		Hydrology	X		X		
		Microbial Contamination	X				
		Organic Enrichment	X		X		
		Sedimentation					X
		Toxics					X
	Fish Ponds	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology			X		
		Invasives			X		
		Microbial Contamination		X			
		Organic Enrichment		X	X		
		Sedimentation			X		
		Toxics					X
	Wetlands	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contamination	X				
		X					
		Toxics					X

PARK	RESOURCE	STRESSOR(S)	long-term	short-term	ACTIVITY STAGE in-prep	suspended	unaddressed
	Nearshore/coastal	Climate Change					X
		Hydrology			X		
		Invasives					X
		Microbial Contamination	X	X			
		Organic Enrichment	X	X			
		Sedimentation			X		
		Toxics					X

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
PUHE	Streams	Climate Change					X
		Erosion	C				
		Hydrology	C			X	
		Invasives					X
		Microbial Contaminants				X	
		Organic Enrichment					X
		Sedimentation	C				
		Toxics				X	
	Groundwater	Hydrology				X	
		Micobial Contaminants				X	
		Organic Enrichment				X	
		Toxics				X	
	Fish Ponds	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contamination		X			
		Organic Enrichment		X			
		Sedimentation					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contamination	X				
		Organic Enrichment	X				
		Toxics					X
	Nearshore/coastal	Climate Change					X
		Hydrology			X		
		Invasives					X
		Microbial Contamination		X			
		Organic Enrichment		X			
		Sedimentation			X		
		Toxics					X

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
KAHO	Groundwater	Hydrology				X	
		Hydrology			X		
		Microbial Contamination	X			X	
		Organic Enrichment	X		X	X	
		Toxics				X	
	Anchialine Pools	Atmospheric Deposition					
		Climate Change					X
		Hydrology			X		
		Invasives					X
		Microbial Contamination	X				
		Organic Enrichment	X		X		
		Sedimentation					X
		Toxics					X
	Fish Ponds	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology			X		
		Invasives			X		
		Microbial Contaminants					X
		Organic Enrichment			X		
		Sedimentation			X		
		Toxics					X
	Wetlands	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contamination	X				

PARK	RESOURCE	STRESSOR(S)	long-term	short-term	ACTIVITY STAGE in-prep	suspended	unaddressed
		Organic Enrichment	X				
		Toxics					X
	Nearshore/coastal	Climate Change					X
		Hydrology					X
		Invasives					X
		Microbial Contamination	X				
		Organic Enrichment	X				
		Sedimentation					X
		Toxics					X

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
PUHO	Streams	Climate Change					X
		Erosion					X
		Hydrology				X	
		Invasives					X
		Microbial Contamination				X	
		Organic Enrichment				X	
		Sedimentation					X
		Toxics				X	
	Groundwater	Hydrology				X	
		Micobial Contaminants				X	
		Organic Enrichment				X	
		Toxics				X	
	Anchialine Pools	Atmosheric Deposition					X
		Climate Change					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Fish Ponds	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change					X

PARK	RESOURCE	STRESSOR(S)	long-term	short-term	ACTIVITY STAGE in-prep	suspended	unaddressed
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Submerged Spring	Hydrology					X
		Microbial Contamination					X
		Organic Enrichment					X
		Toxics					X
		Sedimentation					X

PARK	RESOURCE	STRESSOR(S)	ACTIVITY STAGE				
			long-term	short-term	in-prep	suspended	unaddressed
HAVO	Streams	Climate Change					X
		Erosion					X
		Hydrology				X	
		Invasives					X
		Microbial Contamination				X	
		Organic Enrichment				X	
		Sedimentation					X
		Toxics				X	
	Groundwater	Hydrology				X	
		Micobial Contaminants				X	
		Organic Enrichment				X	
		Toxics				X	
	Anchialine Pools	Atmosheric Deposition					X
		Climate Change			X		
		Hydrology			X		
		Invasives			X		
		Microbial Contaminants					X
		Organic Enrichment			X		
		Sedimentation					X
		Toxics					X
	Wetlands	Atmosheric Deposition					X
		Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X
	Beaches	Climate Change					X
		Erosion					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Toxics					X
	Nearshore/coastal	Climate Change					X
		Hydrology					X
		Invasives					X
		Microbial Contaminants					X
		Organic Enrichment					X
		Sedimentation					X
		Toxics					X

Appendix G: Proposed Water Quality Boundaries

The following is the link to the maps showing proposed boundaries for water quality monitoring within each PACN park.

http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/waterq.htm